United States Patent

Tuchen

[15] **3,668,565**

[45] **June 6, 1972**

[54] LOW PROFILE WAVEGUIDE CHANNEL DIPLEXER

[72] Inventor: **Gerd Achim Tuchen**, Boxford, Mass.

[73] Assignee: **Bell Telephone Laboratories, Incorporated**, Murray Hill, N.J.

[22] Filed: **Apr. 16, 1971**

[21] Appl. No.: **134,806**

[52] **U.S. Cl.** .....**333/6**, 333/21 R, 333/73 W, 333/83 R

[51] **Int. Cl.** **H01p 5/12**

[58] **Field of Search** .....333/6, 9, 21 R, 21 A, 73 W, 333/95 R, 98 R

[56] **References Cited**

UNITED STATES PATENTS

3,112,460	11/1963	Miller	333/9
3,321,720	5/1967	Shimada	333/21 R X

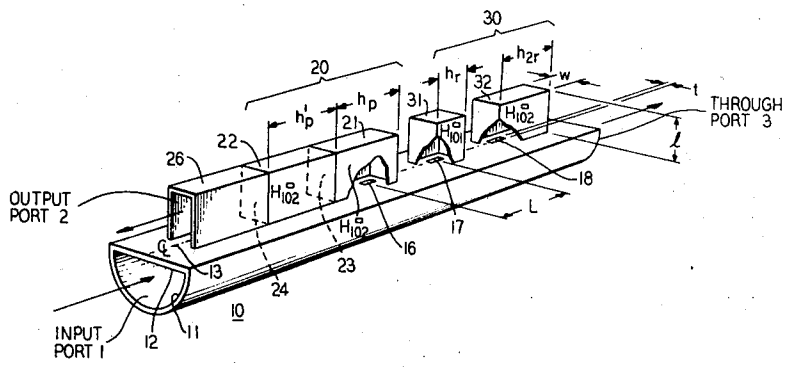
Primary Examiner—Paul L. Gensler

Attorney—R. J. Guenther and E. W. Adams, Jr.

[57] **ABSTRACT**

A waveguide channel diplexer in which plural resonant rectangular cavities are coupled to a segmented circular waveguide through thin slots on a plane longitudinal surface of the guide. The slots are located to preserve circular symmetry and consequently the purity of the circular electric mode; the cavities which produce a complementary bandpass-bindstop filter pair are designed to be electroformed from permanent mandrels.

7 Claims, 2 Drawing Figures



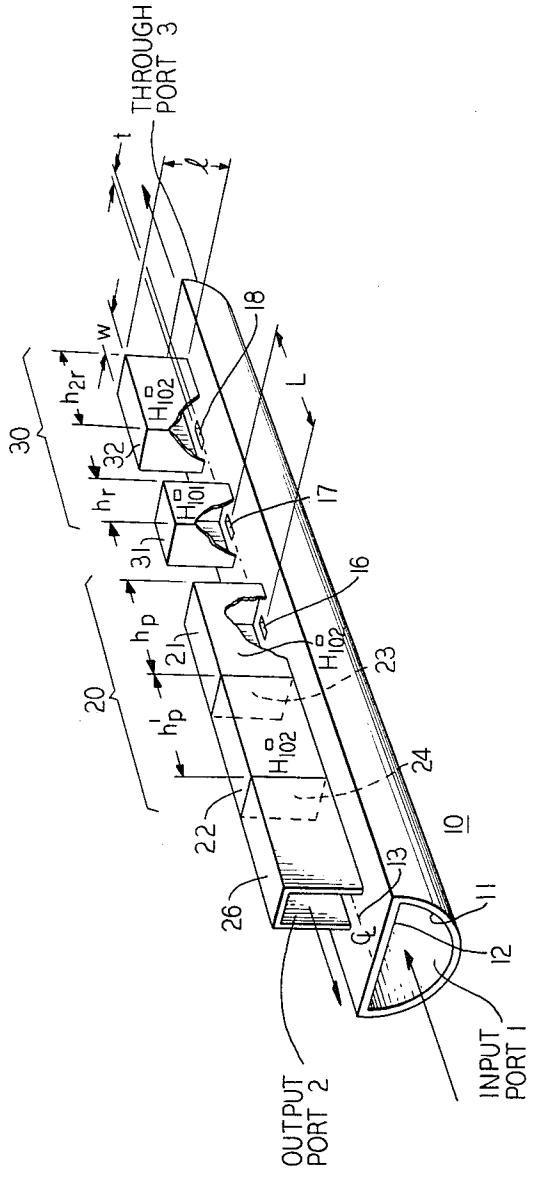
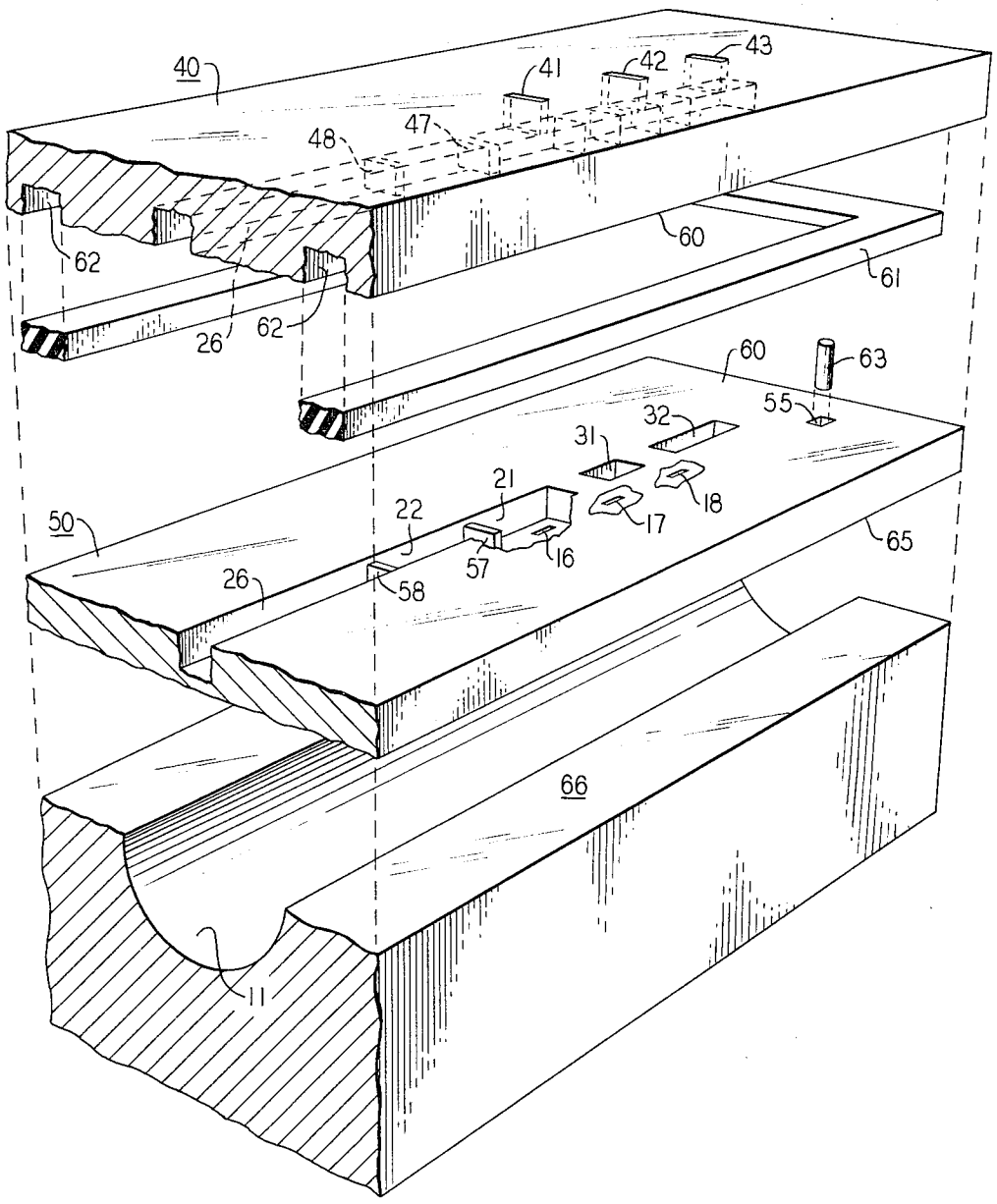


FIG. 1

INVENTOR
G. A. TUCHEN
BY David L. Genens
ATTORNEY

FIG. 2


40
41
42
43
47
48
62
60
61
26
62
60
63
55
32
31
21
22
18
17
16
57
58
50
26
65
66
11

LOW PROFILE WAVEGUIDE CHANNEL DIPLEXER

BACKGROUND OF THE INVENTION

This invention relates to electromagnetic waveguide transmission and more particularly to waveguide mode transducing devices, especially a complementary bandpass-bandstop filter which may be used for channel dropping or channel combining in a millimeter wave transmission system.

The TE_{01}° circular electric mode of wave propagation in circular waveguides has received considerable attention due to its recognized low-loss propagation characteristic which exhibits decreasing loss with increasing frequency. The problem of multiplexing in a communication system using this mode of wave propagation was first considered by E. A. J. Marcatili in his article entitled "Mode-Conversion Filters," published in the January 1961 issue of the Bell System Technical Journal, pages 149–184. The filters described by Marcatili in this article, and in his U.S. Pat. No. 2,963,663, use high loss-narrow bandwidth coaxial cavities.

The high loss of a coaxial cavity, which is formed from rectangular waveguide wrapped around a cylinder such as a circular waveguide wall, causes the overall filter loss to considerable if many such cavities are used. Some of the filters utilize circular electric mode conversion resonators to achieve channel separation. These exhibit an extremely low loss, but provide only a single bandpass section, and for multipole arrangements, additional bandpass sections of the coaxial cavity type are required. This, of course, introduces substantial loss and severe bandwidth limitations.

Coupling to the coaxial cavity is provided through a distributed arrangement of apertures in the circumferential wall. Due to the circular geometry, it is difficult and costly to fabricate the cavities and the appropriate aperture arrangement. In addition, both the mode conversion resonator and the coaxial resonator exhibit relatively narrow frequency bands which are free from spurious resonances. In certain transmission systems, it is essential to have channel diplexers capable of operating over as broad a bandwidth as possible and many system applications require a band broader than these cavities provide. Improvements which would increase bandwidth and simplify the structural arrangement would make the device more attractive.

The desirable TE_{01}° mode, which exhibits a longitudinal component that is exclusively magnetic (H_z) and is therefore alternatively designated the H_{01} circular or H_{01}° mode, may be propagated in a segmented circular waveguide. As used herein, a segmented circular waveguide means a waveguide having a cross-section which is a segment of a circle, such as a semicircle, and the resulting chordal surface is the plane surface containing the chord of the cross-sectional segment, or the diameter of the segment is a semicircle. The longitudinal magnetic component H_z is maximum at the center line of the chordal surface, and it is thus possible to couple directly to this mode at this central location. There have been previous attempts to couple to a plane surface of a segmented waveguide, such as is disclosed in U.S. Pat. No. 3,112,460 to S. E. Miller. However, these arrangements require bifurcating a circular guide into two parallel semicircular guides and coupling equal amounts of incident energy into each. Both of the parallel semicircular guides are coupled to the output port with critical dimensions arranged so that the half of the energy arriving at the output guide from one of the semicircular guides is out-of-phase with the other half of the energy arriving from the other semicircular guide, thereby preventing any of the incident energy from coupling to the output guide. A frequency selective reflecting device in each of the semicircular guides causes energy at the selected frequency to return to the apertures and a 180° phase delay must be provided in one guide to insure the desired coupling to the output port. This complex arrangement is, of course, difficult to fabricate.

SUMMARY OF THE INVENTION

In accordance with the present invention, a channel diplexer is provided which offers fabrication simplification and broader bandwidth than the previous filter designs without significantly sacrificing the low-loss characteristics of the circular electric mode propagation. The main through waveguide is a single segmented waveguide, and cavities are mounted directly on the chordal surface. The cavities which are preferably complementary bandpass and band rejection filters, are tuned to resonate at a specified channel frequency. Coupling to the longitudinal magnetic component is made along the center line of the chordal surface by means of a single aperture for each cavity. Since all the coupling apertures are located on a plane surface, rather than in the more complex circumferential distribution required to couple to coaxial cavities, a substantial cost reduction over that type of filter is realized; there is also a substantial reduction over the cost of the parallel semicircular arrangement.

A segmented circular guide exhibits a low through loss characteristic similar to that of a circular guide. Through loss in a circular waveguide is slightly lower than that in a segmented guide of the same diameter, but the loss in the segmented guide is still effectively negligible and is a small price to pay for the large increase in bandwidth offered by the segmented structure. In one typical system application, the input wave in the main waveguide could have a percentage bandwidth greater than 15 percent. These bandwidths are substantially higher than can be provided if the main waveguide were circular in cross-section.

The present invention is an improved version of the channel diplexer claimed in the copending application of C. Ren and H. Wang, Ser. No. 134,805, filed on an even date herewith and assigned to the assignee hereof. The improved diplexer is envisioned as part of a tandem arrangement of numerous similar diplexers in a millimeter wave multiplexer. It may, of course, have other applications.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a perspective view of a channel diplexer in accordance with the present invention; and

FIG. **2** included for purposes of explanation, is an exploded view of an electroformed embodiment of the diplexer of FIG. **1**.

DETAILED DESCRIPTION

FIG. **1** illustrates a two-pole channel diplexer in accordance with the invention comprising a two-cavity branching filter **20** and a two-cavity band rejection filter **30** longitudinally disposed along segmented waveguide **10**. Waveguide **10** is proportioned to support a continuous range of frequencies in the H_{01}° mode, including channel bands centered at $f_1, f_2 \ldots f_n$. Hereinafter, this range is referred to as the subband, and each channel is designated by its center frequency.

Segmented circular waveguide **10** is conductively bounded by circumferential wall **11** and plane surface **12**. In order to preserve the circular symmetry of the electric and magnetic field patterns propagating in waveguide **10** and hence avoid unwanted moding, the waveguide is designed so that the chordal surface **12** contains the diameter of the circular cross-section; i.e., waveguide **10** is a semicircular waveguide.

In a millimeter wave multiplexer, a large number of channel diplexers are arranged in tandem. In such a system it is preferable to have as wide a subband bandwidth as possible and if the diameter of waveguide **10** is properly chosen a percentage bandwidth (free of cut-off for any mode) which is approximately 18 percent may be established. The subband is located between the cut-off frequencies of the higher order circular modes H_{12}° and E_{31}°. It is noted that the circular magnetic mode E_{02}° would prevent such a wide bandwidth; this mode is present in circular guides, but is not supported by the segmented guide. Therefore, the subband propagating in waveguide **10** is wider than that in a circular guide.

The $H_{01}°$ mode propagates in the segmented waveguide with an extremely low-loss characteristic. The magnitude of the loss is slightly greater in a segmented guide than a circular guide of the same diameter, due to the additional loss from the induced surface currents on the flat chordal surface. The increased loss is, however, extremely small and even if it were on the order of twice as large, the channel diplexer loss would still be insignificant relative to the loss provided by the more conventional rectangular waveguide.

The diplexer is shown and described as a channel dropping filter with the subband signal $f_1, f_2 \ldots f_n$ entering Input Port **1**, the dropped channel of frequency f_i propagating out at Output Port **2**, and the remainder of the subband signal after the dropped channel has been removed propagating out at through Port **3**, but the diplexer is, of course, reciprocal and may also be used as a channel combiner.

The incoming subband signal containing a combination of channels propagates in the $H_{01}°$ mode. The channel which is to be dropped is coupled into branching filter **20**. Branching filter **20**, together with the two-cavity band rejection filter **30**, forms a two-pole filter of complementary design. Thus, the through channels $f_1, f_2 \ldots f_{(i-1)}, f_{(i+1)}, \ldots f_n$ will propagate down waveguide **10** under matched conditions.

Branching filter **20** contains two rectangular cavities **21** and **22**, which are end-coupled by inductive coupling through their mutual wall **23**. Rejection filter **30** contains two rectangular cavities **31** and **32**. Cavities **21**, **31** and **32** are longitudinally coupled to waveguide **10** through coupling apertures **16**, **17** and **18**, respectively, located on chordal surface **12**. Each cavity must have its magnetic field component aligned with the thin coupling slot in the common wall between the cavity and surface **12**. These coupling apertures are oriented along the center longitudinal axis **13** of the chordal surface so that the presence of these apertures preserves the circular symmetry of the structure with respect to the fields of the incoming waves of $H_{01}°$ mode. In order to avoid moding problems, the apertures are slots which are thin relative to the diameter of waveguide **10**. These slots, which may be rectangular or elliptical, couple only energy from the circular $H_{0m}°$ mode to the cavities. But since $H_{0m}°$ frequencies are below cut-off for $m \geq 2$, only $H_{01}°$ will excite the cavities, and the diplexer will not respond to incoming signals in any spurious modes.

The longitudinal magnetic field in waveguide **10** is maximum along center line **13** of surface **12**, and since thin slot apertures **16**, **17** and **18** are located along this line, strong coupling to the longitudinal component of the cavity resonant mode is provided. The magnetic field at this location is, for example, several times larger than the longitudinal magnetic field of the $H_{01}°$ mode in the circular waveguide on its circumferential waveguide wall.

Branching filter **20** and band rejection filter **30** are dimensioned so that their cavities resonate at f_i, the center frequency of the channel to be dropped. This is accomplished by choosing suitable cavity dimensions as described hereinafter. Thus, the desired channel f_i is coupled to Output Port **2** and the rejection cavities turn back energy in this frequency band, preventing its passage to Through Port **3**. The bandpass and band rejection cavities are designed as a complementary pair and each has the conventional maximally flat frequency response characteristic within the operating subband, so that constant resistance will be seen looking into Input Port **1**.

Any oversized (overmoded) waveguide may be used for the resonance cavities to achieve a higher intrinsic Q for the resonant mode which may be either the dominant or higher order mode. However, if the cavity dimensions are large enough to allow higher order modes, frequencies in the subband $f_1 \ldots f_n$ outside the desired channel band f_i may be resonant for such higher modes. Therefore, for broad subband bandwidth, the cavity dimensions should be chosen so that no spurious resonance exists at frequencies within the subband. The dominant H_{10i} mode will provide the widest operating bandwidth, but higher order H_{10n} modes may be attractive for certain applications, particularly where low loss is more important than greatest subband bandwidth.

The cavities are positioned so that the narrow dimension w of the cavity cross-section lies on surface **12** and is perpendicular to the axis of waveguide **10**; the broad cross-sectional dimension l is perpendicular to surface **12**. The length of each cavity is designated h, and it is oriented parallel to the propagation in waveguide **10**. For a resonant frequency of f_i and lowest loss, the cavity length must be approximately equal to n times the dimension l which, in turn, must be approximately equal to $\lambda_i/\sqrt{2}$, where n is the order of the resonant H_{10n} mode and λ_i is the free-space resonance wavelength at f_i.

In FIG. **1** the "most downguide" rejection cavity **32** is shown having a length h_{2r}, approximately twice the length of rejection cavity **31**. Cavity **32** supports the H_{102} mode, while cavity **31** supports the H_{101} mode. Likewise, bandpass filter **20** may be dimensioned for higher order modes and cavity **21** has a length h_p substantially equal to h_{2r}. The second bandpass cavity **22** also supports the H_{102} mode and has a length h_p' which is approximately equal to h_p. It is positioned "upguide" from and inductively coupled through their mutual end wall **23** to cavity **21**. The dominant mode may be used throughout the structure but the higher order modes result in lower loss.

Coupling slots **16**, **17** and **18** are located on center line **13** of surface **12** and separated by a center-to-center distance L which is an odd multiple of one-quarter λ_i'; λ_i' is the guide wavelength of the $H_{01}°$ mode in waveguide **10**. The coupling slot is centrally located on the length h of a dominant mode cavity such as **31**, and the increased length of the higher order cavities, such as **21** and **32**, does not alter the relative location of the slot and the nearest end wall of the cavity. Cavity **22** is coupled to waveguide **10** only through cavity **21**.

The energy at frequency f_i in the resonant mode may be coupled from cavity **22** to Output Port **2** in any physical manner so long as it is compatible with the electrical design and causes no moding problems. The simplest form is an inductive coupling through end wall **24**. It is anticipated that output waveguide **26** will continue the narrow dimension w of the cavities for a significant distance and guide **26** may thus be oversized in width and require a transducer for the conversion to standard waveguide. Waveguide **26** which is beyond the diplexer region may, of course, be turned to facilitate system design.

Since all of the cavities lie on surface **12** and extend above surface **12** by the same broad dimension l, the diplexer of FIG. **1** is referred to as having a low (or horizontal) profile in distinction to the diplexers having varying heights above surface **12**, such as are disclosed in the aforementioned copending application of Ren and Wang. The low profile offers a number of significant mechanical advantages. Primarily, the diplexer can be fabricated by a simple electroforming process which requires that any protrusions and indentations of the mandrel be shallow to facilitate deposition in the concave mandrel recesses. FIG. **2** is an exploded view of the electroformed components of the low profile diplexer.

The two components, an upper portion **40** and a lower portion **50** form the cavities, and due to the selection of a suitable mating plane in the low profile geometry and the use of inductive obstacles **47**, **48**, **57** and **58**, instead of other coupling means the two mandrels used for electroforming can be readily extracted and, therefore, may be of the permanent type. High profile designs require destruction of the mandrels (referred to as "lost" mandrels), and hence different production models of those diplexers are subject to variations. The permanence of the mandrels for the low profile design make possible precise reproduction of all diplexers for the same channel frequency. As can be seen, the two electroformed portions **40** and **50** combine to produce, in addition to the resonance cavities **21**, **22**, **31** and **32**, all of the coupling apertures **16**, **17** and **18** and the output waveguide **26** as shown in FIG. **1**. In addition, access openings for tuning, such as **41**, **42** and **43** may be provided in upper portion **40** and alignment holes, such as **55** in the lower portion **50** and corresponding holes (not shown) in the underside of upper portion **40**, can also be generated. Tuning openings **41**, **42** and **43** may be of

any desired shape suitable for tuning elements, such as a capacitive screw or preferably a magnetic field displacement vane. It is noted that the electroforming process may produce a channel for output waveguide **26** which is considerably longer than is shown and in addition this output channel may be turned upward into portion **40** to form a vertical output port.

The rectangular geometry, particularly that having constant narrow dimensions w and t, facilitates extremely precise, and economical mandrel fabrication by means of profile grinding. The inductive end walls **23** and **24** are "grown in," that is, an additional piece of material is inserted into precisely located and precisely machined slots in the mandrel after it is cleaned so that the resulting electroformed portions **40** and **50** include protrusions **47** and **57**, and **48** and **58** which combine to form conductive walls **23** and **24**, respectively.

The mass precision production of all of these elements makes fabrication substantially simpler and less costly than other manufacturing processes required for diplexers of other geometries.

The low profile geometry yields additional advantages. Since the permanent mandrels do not need to be dissolved, they may be formed of a stable material such as an austenitic stainless steel. Without other constraints the permanent mandrel material may be chosen to resist the corrosive attack of a plating solution, such as sulfuric acid, which will produce a high conductivity electroformed product. The cavity walls of a low profile diplexer can thus have higher conductivity than is attainable using the lost mandrels required to produce high profile designs.

The low profile geometry also allows mating plane **60** to be located midway between the narrow walls of the cavities and hence along a line which is not crossed by electric currents in the desired mode.

If the broad cavity dimension l is to be approximately 100 mils, the upper portion **40** would be approximately 100 mils thick with 50 mil indentations forming the upper halves of the cavities. The thickness of portion **40** contributes physical strength to the diplexers. Similarly, the lower portion **50** would have 50 mil indentations, but the remaining part of portion **50** may be machined down to form a surface **65** which is separated from the narrow cavity walls by a very small distance such as 10 mils. This ground surface **65** then forms the chordal plane of segmented waveguide **10**. The circumferential wall **11** can be formed by electroforming a block **66** around a lost mandrel which is secured to ground plane **65** and appropriately aligned with apertures **16**, **17** and **18**. The electroforming will cause block **66** to fuse to surface **65**.

After fusing surface **65** to block **56** the upper and lower portions **40** and **50** are readily sealed along mating plane **60** by tapped holes and screws not shown. Alignment holes, such as **55**, and their corresponding holes in portion **40**, insure precise alignment of the cavities. A commercially available round pin, such as **63**, is inserted between the corresponding holes which may be square to facilitate production by the electroforming process. Gasket **61** fits in its channel **62**, which may be machined in upper portion **40**. This provides a good pneumatic seal which is required if a dry gas (such as nitrogen) is to be maintained under pressure within the diplexer structure. A commercially

Any diplexer, in which rectangular cavities are mounted on a chordal surface of a segmented waveguide so that one wall of each cavity lies in a single common plane located a fixed distance from the chordal surface, has a low profile design and offers the aforementioned mechanical advantages and the resultant economies of fabrication.

In all cases it is to be understood that the above-described arrangements are merely illustrative of a small number of the many possible applications of the principles of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A waveguide transmission device comprising a conductivity bounded waveguide having a curved surface and a single plane surface and capable of propagating energy in a circular electrode mode, a bandpass cavity capable of supporting a resonant mode and mounted on the single plane surface of the waveguide, and means comprising a single aperture in the single plane surface for exclusively coupling energy between the circular electric mode in the waveguide and the resonant mode in the bandpass cavity, said bandpass cavity being a rectangular prism positioned so that the narrow cross-sectional dimension of the bandpass cavity lies on the single plane surface perpendicular to the axis of the waveguide.

2. A waveguide transmission device comprising, a segmented circular waveguide capable of supporting the H_{01} circular electric mode and having a circumferential surface and a plane chordal surface parallel to the axis of the waveguide, a primary bandpass resonant cavity of rectangular cross-section having selected narrow and broad dimensions and mounted on the chordal surface, a pair of band rejection resonant cavities of rectangular cross-section having said selected narrow and broad dimensions and mounted on the chordal surface downguide from the primary bandpass cavity, at least one thin aperture for the primary bandpass cavity and for each band rejection cavity located on the chordal surface for coupling between the H_{01} circular electric mode of the waveguide and the resonant mode of the cavity, a secondary bandpass cavity having selected narrow and broad dimensions and mounted on the chordal surface, said secondary bandpass cavity being positioned upguide from said primary bandpass cavity longitudinally end-to-end with the primary bandpass cavity and coupled thereto through their mutual end wall, all of said cavities having a dimension chosen so that each cavity supports a resonant H_{10n} rectangular mode in a common frequency band, and an output port coupled to said secondary bandpass cavity.

3. A waveguide transmission device as claimed in claim **2** wherein the narrow cross-sectional dimension of each cavity lies on the chordal surface perpendicular to the axis of the waveguide.

4. A waveguide transmission device as claimed in claim **2** wherein said segmented circular waveguide has a semicircular cross-section.

5. A waveguide transmission device as claimed in claim **2** wherein the length of each cavity is selected so that $n = 2$ for at least one of said cavities.

6. A waveguide transmission device as claimed in claim **2** wherein each of said cavities are mounted so that one wall of each cavity lies in a single common plane located a fixed distance from the chordal surface.

7. A waveguide transmission device as claimed in claim **2** wherein said cavities and the output waveguide have a common narrow dimension w and common narrow dimension t of the coupling apertures.

* * * * *