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FILTER FOR PASSING SELECTED TE CIRCULAR MODE AND
ABSORBING OTHER TE CIRCULAR MODES

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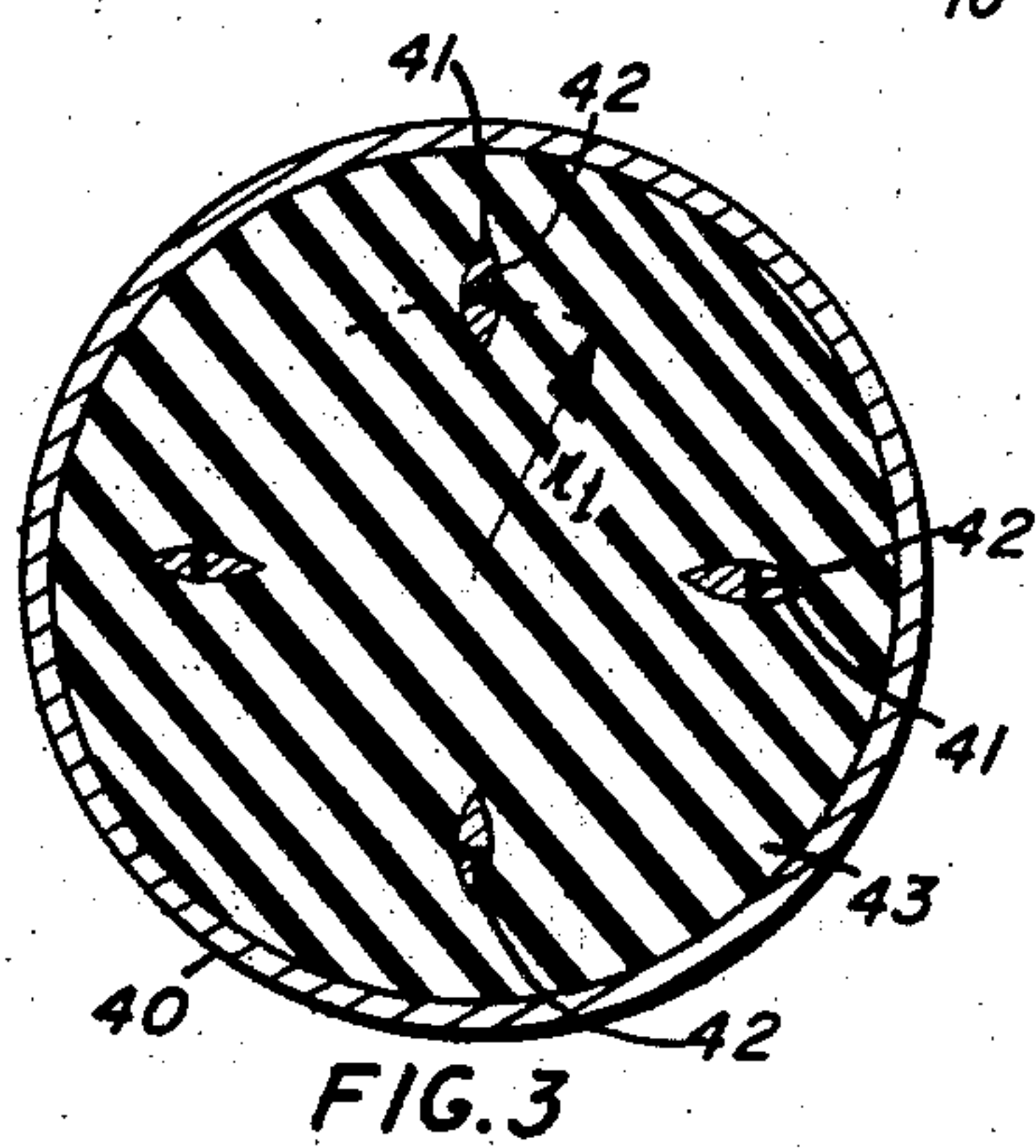
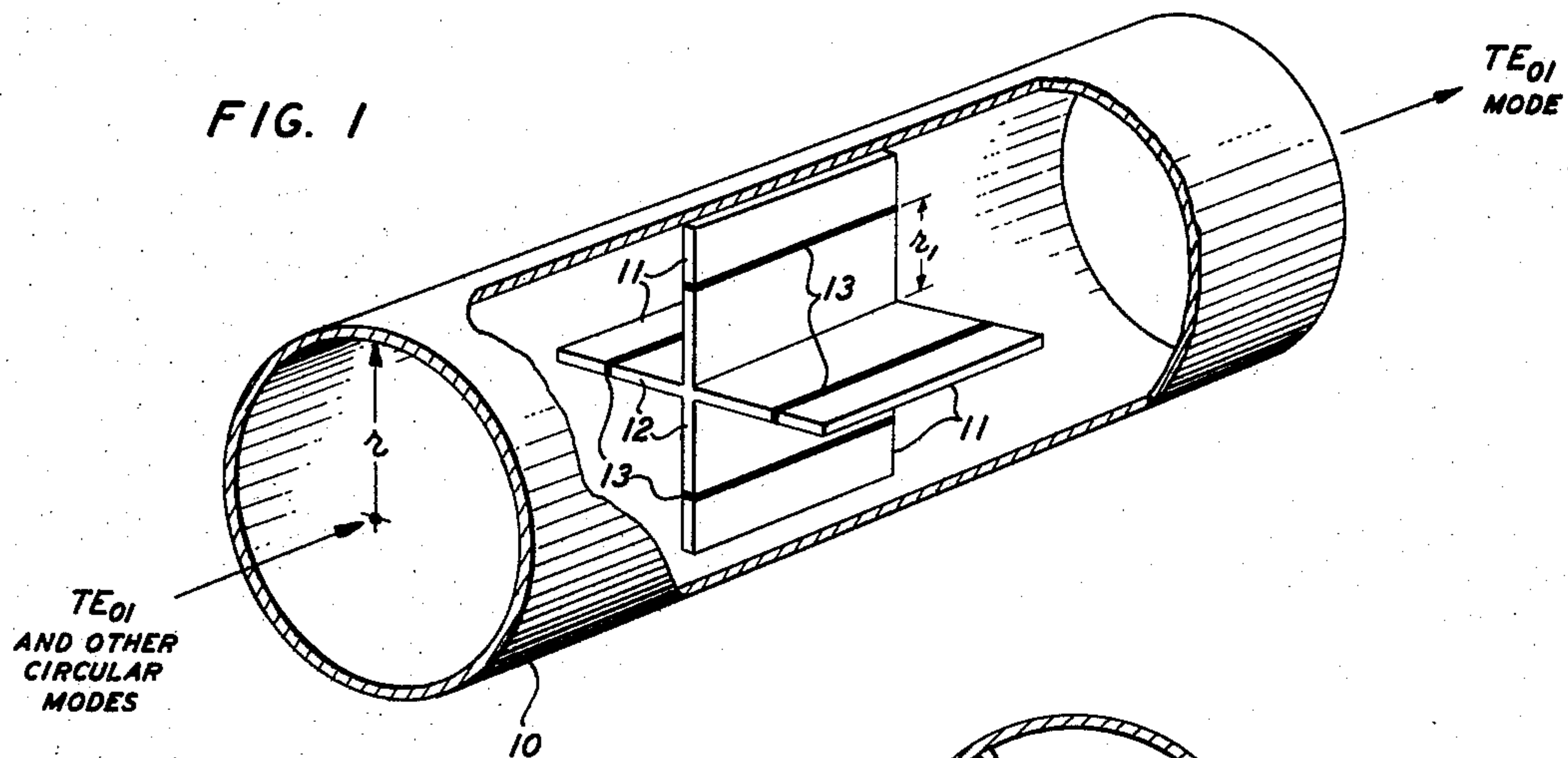


FIG. 2

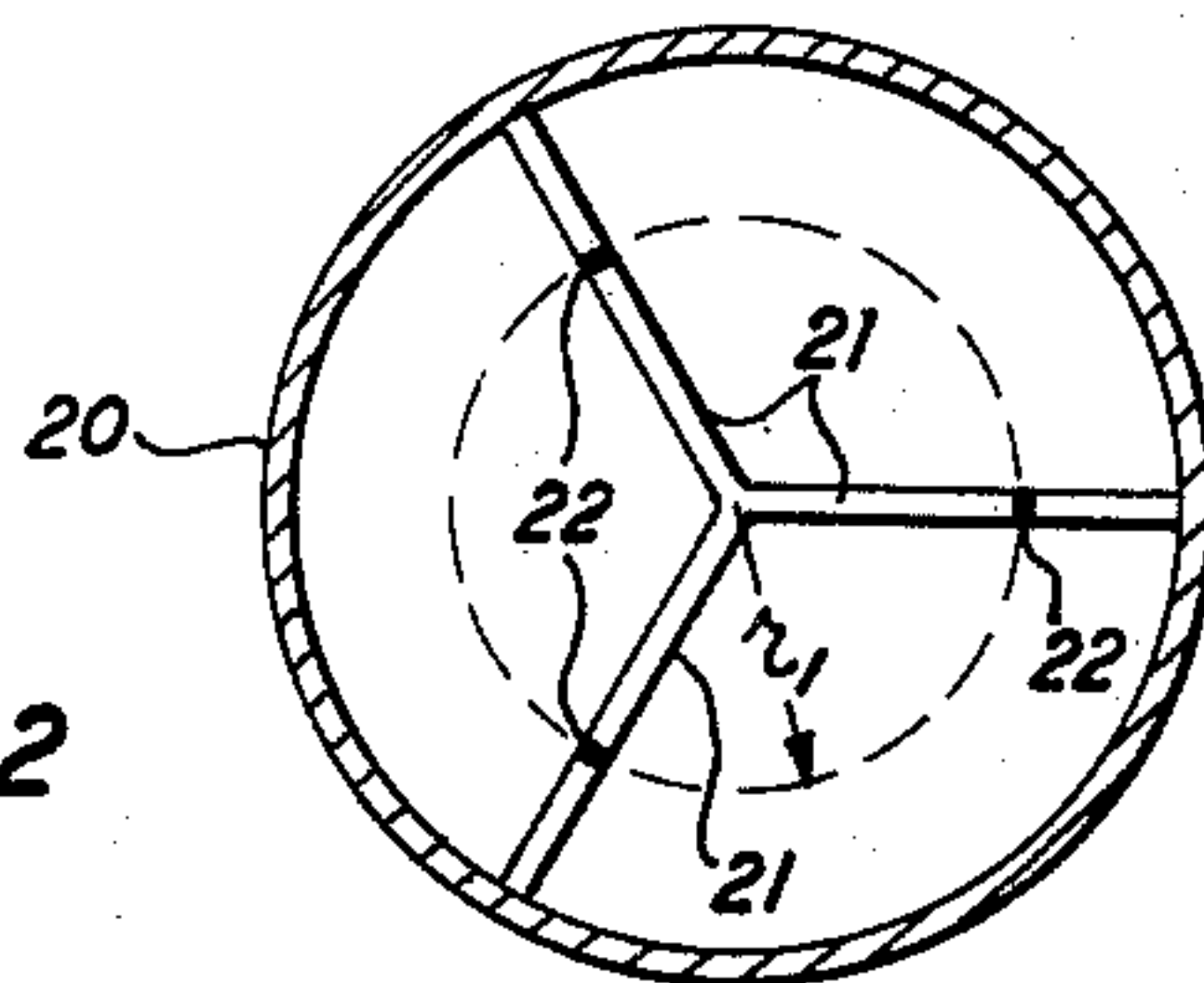
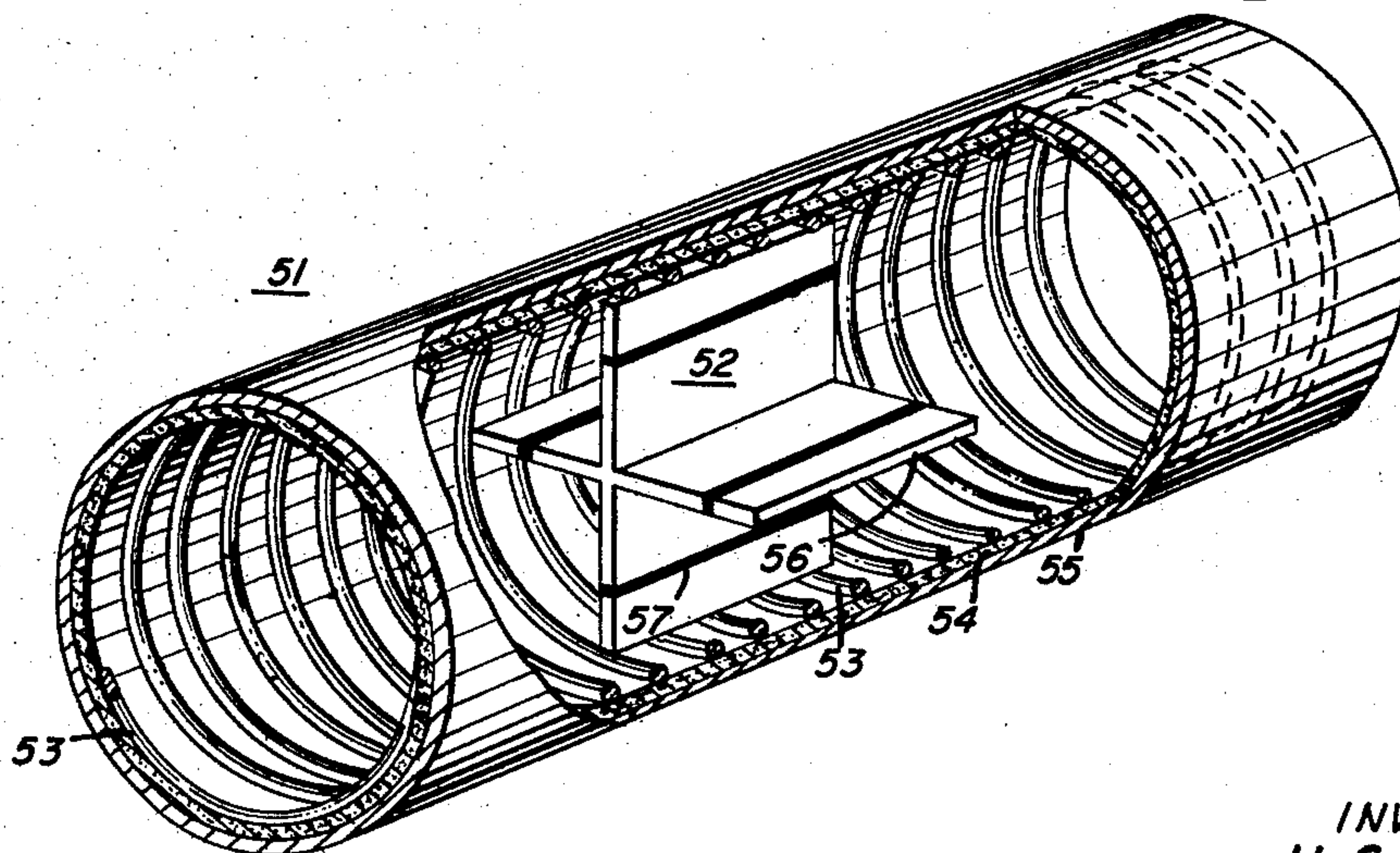


FIG. 4



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FILTER FOR PASSING SELECTED TE CIRCULAR MODE AND ABSORBING OTHER TE CIRCULAR MODES

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This invention relates to electromagnetic wave transmission systems whose primary mode of propagation is the TE_{01} circular electric mode, and more particularly to mode filters for selectively attenuating all but a selected one of the plurality of circular electric modes generally present in such systems.

In the transmission of electromagnetic wave energy in a hollow pipe or other type wave guide, it is well known that the energy can be supported in a number of transmission modes, or characteristic electric and magnetic field configurations, depending upon the cross sectional size and shape of the guide itself and upon the operating frequency selected. It is also well known that the larger the cross section of the guide, or the higher the operating frequency, the greater is the number of modes which may be supported at a given operating frequency or within a guide of a given cross section, respectively. Generally it is desirable to confine the energy propagation to one particular mode, chosen because its propagation characteristics are particularly suited to the specific application involved. However, other considerations may dictate the use of guide sizes which accommodate not only the desired mode but also other higher order modes of the same family as well as modes having other basic configurations. This is particularly true of systems utilizing TE_{01} circular electric waves. Propagation of microwave energy in the TE_{01} mode is well known to be ideally suited to long distance transmission of high frequency wide band signals since the attenuation characteristic of this mode, unlike that of other modes, decreases with increasing frequency. Furthermore, transmission losses associated with the TE_{01} mode are inversely proportional to the guide diameter. Thus current practice, whenever possible, is to use uninterrupted runs of relatively large diameter pipe for long runs in an all wave guide system. However, the use of large diameter pipe causes the system to be susceptible to generation of the unwanted, or spurious, modes which, due to the large diameter pipe, propagate concurrently with the desired mode.

In an ideal system utilizing a guide which is perfectly straight, uniform, and conducting, propagation of TE_{01} waves therethrough would be undisturbed, and the fact that the guide is capable of supporting other modes, once launched, is not a problem. However, terminal operations and pipe curvature within the system, as well as inherent imperfections in the guiding member itself tend to disturb the TE_{01} mode and to cause conversion of power from this mode into other unwanted modes. These latter modes are perfectly capable of being propagated in the system and therefore have a deleterious effect upon the transmission of information through the system. Obviously every reasonable effort must be made to minimize this spurious mode generation process by appropriate methods and means. However, from a standpoint of practical economics, there is a spurious mode level below which one should not attempt to go. It thus becomes necessary to accept this spurious mode level in practice and to provide intermittently spaced mode filtering means along the transmission path periodically to reduce the power level of the unwanted modes.

In the past it has been recognized that there are two

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general classifications into which the unwanted modes fall. The first class comprises both the noncircular, asymmetric modes and the circular symmetric magnetic modes which may be relatively easily removed from the system by means of a helix type wave guide for example. The second class comprises higher order circular electric modes of the circularly symmetric family which are not so readily removable since their field patterns are somewhat similar to that of the TE_{01} mode. In the past, filtering techniques useful for removing the noncircular modes and the circular magnetic modes have been ineffective for removing the higher order circular electric modes. Furthermore, filtering arrangements which efficiently removed the higher order circular electric waves either adversely affected the TE_{01} mode or were structurally somewhat difficult to fabricate and assemble.

It is therefore an object of this invention selectively to attenuate wave modes of the circular electric family to the exclusion of the TE_{01} mode and to transmit the latter mode unaffected.

In the copending application of R. Kompfner et al., Serial No. 809,088, filed April 27, 1959, now United States Patent 3,041,559, issued June 26, 1962 there are disclosed gyromagnetic methods and means for selectively attenuating the higher order circular electric modes in a TE_{01} transmission system. However, in certain applications the magnetic polarization required in accordance with the Kompfner et al, disclosure may prohibit use of that filter. The present invention thus represents an alternate means of selective circular electric mode filtering.

In accordance with the present invention, dissipation of electric currents generated in conductive material is utilized to provide the loss mechanism for the attenuation of power in unwanted mode configurations. In specific embodiments of the invention, conductive metallic vanes or segments, each containing a gap filled with material capable of dissipating electric currents flowing across the gap, are disposed within a circular wave guide with the gaps positioned at locations for which the desired circular electric mode generates no radial currents. At the same time all other circular electric modes generate currents of varying degrees within the lossy gap and thereby suffer attenuation. In particular if the gap in the metallic member is located at a radial distance equal to 0.628 of the total radius of the guide, the TE_{01} mode produces a radial current null at the gap and will therefore be substantially unaffected by the vane. Other modes, particularly the TE_{02} mode, have substantial radial current densities at this location and are therefore significantly attenuated.

It is therefore a further object of the present invention to attenuate higher order circular electric wave modes to the exclusion of the TE_{01} mode by means dependent upon electrical current dissipation effects.

According to a first preferred embodiment of the invention a plurality of highly conductive vanes or thin plates extend within a hollow circular pipe between the center and the outside wall along various radii thereof. At a certain radial distance along each vane, which distance may be designated r_1 , the electromagnetic field of the desired wave mode induces no radial currents in the metal vane. At this particular radial location a gap is introduced into the metal vane and the gap is filled with resistive material capable of attenuating electric currents which extend across the gap. This resistance gap continues for the longitudinal extent of the vane, always at the prescribed radius r_1 from the central axis of the guide. In the metallic vanes the unwanted circular electric modes are characterized by non-zero radial current densities at the resistance gap and therefore power from these modes is dissipated in the resistive material. Thus the power

level of the unwanted modes is reduced while the power level of the desired mode remains substantially unaffected.

In a second embodiment of the invention the metallic members take the form of segments which extend only a portion of the distance between the guide axis and the boundary wall. The metallic segments are tapered at their extremities and appear ovoid in transverse cross section. The radial extent of each segment is limited to the immediate vicinity of the radial location at which induced radial currents of the desired mode are minimum, and the resistance gap is positioned at this radial current minimum. By thus limiting the transverse extent of each of the metallic members, perturbations of the desired mode are minimized.

When either of the above-described embodiments are combined with a lossy jacketed helix or spaced ring type wave guide, over-all transmission characteristics superior to those realizable in either guide alone result. This is due to the fact that the conductive members with resistance gap attenuate the spurious modes of the circular electric family and the lossy jacket surrounding the main guiding means attenuates the asymmetric and circular magnetic spurious modes generated both by inherent imperfections and curvature and by the introduction of the metallic members themselves into the transmission path.

These and other objects and advantages, together with the nature of the present invention, and the various features, will appear more fully upon consideration of the illustrative embodiments to be described in detail below and shown in the accompanying drawing, in which:

FIG. 1 is a partially broken away perspective view of a mode filter in accordance with a first embodiment of the invention;

FIG. 2 is a transverse cross sectional view of a modification of the mode filter of FIG. 1;

FIG. 3 is a transverse cross sectional view of a mode filter in accordance with a second embodiment of the invention; and

FIG. 4 is a perspective view of a mode filter providing filtering action for both circular and noncircular wave modes.

Referring more particularly to FIG. 1, there is shown a section 10 of hollow conductively bounded wave guide having a circular transverse cross section of radius r . The radius r is selected to be sufficiently large to support, at frequencies within the contemplated range of operation, the TE_{01} circular electric mode as well as at least one higher order circular electric mode. Disposed within the cross section of guide 10 and extending radially between the longitudinal axis of the guide and the inner surface of its boundary wall are a plurality of predominantly metallic highly conductive thin flat plates or vanes 11. The vanes need not contact the wall for electrical purposes but it may be desirable that they do contact for mechanical reasons since the vane assembly would be self-supporting in the latter case. As illustrated in FIG. 1 vanes 11 are rectangular in longitudinal cross section, but such a configuration is not intended to be limiting. Indeed it may be desirable that each of the edges 12 be provided with appropriate and well-known impedance matching means such as for example a quarter wave step or a long physical taper. Such impedance matching means have been omitted from FIG. 1, but it should be understood that their use would reduce both wave energy reflection and mode conversion caused by the vanes.

Extending longitudinally parallel to the axis of guide 10 in each of vanes 11 is gap 13, which is filled with an electrically lossy material. Each of gaps 13 has a radial extent of the order of the transverse thickness of the vanes, a dimension to be more fully set out below. The radial location of gaps 13 is critical in that they should be disposed in a region of the field pattern of the desired mode for which this mode induces no radial currents in the metallic vane at the gap location. Since the radial

currents in a radially extending conductive vane in the presence of propagating electromagnetic waves are induced by the longitudinal magnetic components of the waves, the gaps should be located at the null of the longitudinal magnetic field pattern of the desired mode. For the circular electric mode family the radial distribution of the longitudinal magnetic field pattern is a Bessel function distribution. Thus the mean radius r_1 of the lossy gaps 13 is described by the zero of the Bessel function of zero order which describes the radial magnetic distribution of the desired mode.

Since the purpose of the gaps 13 is to dissipate wave mode power, some care must be exercised in the selection of the particular filling material. In general the resistive material should be adapted to dissipate radial current components induced in the vane in the vicinity of the gap by unwanted modes. Resistive material having a specific resistivity of the order of 20 ohm centimeters would be satisfactory. Carbon loaded plastics, carbon loaded paper, and resistance coated glass fibers have been found to have resistivities within the desired range.

The thickness of vanes 11 in a transverse direction is determined by the particular resistance material selected to fill gaps 13. In all cases, the vane thickness is controlled by the skin depth of penetration of the propagating wave energy into the resistance material. Since two opposite surfaces of each gap are subject to energy penetration the vane should have a thickness at least twice the skin depth. In the range of millimeter waves the skin depth in materials of the proper resistivity is of the order of one millimeter. This skin depth is independent of mode and therefore the transverse thickness of a vane for use in millimeter wave applications should be no less than two millimeters. Increasing the vane thickness of course aggravates the reflection problem by virtue of the added metallic volume within the wave path. In this connection it should be noted that the skin depth of penetration of millimeter waves into the conductive portion of each vane is typically in the region of tenths to hundredths of a millimeter. Accordingly, current generation in the vanes is assured when minimum vane thickness is determined by the skin depths associated with the resistance material.

As shown in FIG. 1, vanes 11 extend radially but they need not be spaced at 90-degree intervals as illustrated there nor need there be a total of four vanes. However, the use of four vanes is attractive from symmetry considerations. An alternative arrangement to the four vane embodiment of FIG. 1 is shown in transverse cross section as FIG. 2. Thus in FIG. 2 guide section 20 is loaded with three metallic vanes 21 spaced apart 120 degrees. Resistance gaps 22 are located within each vane at a radial location r_1 , which location is the point of vanishing longitudinal magnetic field for the desired mode of the circular electric family. As the total number of vanes is increased beyond the three or four illustrated the amount of unwanted mode power that is capable of being attenuated is likewise increased but care must be exercised in increasing the total number of vanes too greatly since the total amount of energy reflected from the vanes would increase also.

The operation of the mode selective filters of FIGS. 1 and 2 may now be properly comprehended by considering that a plurality of circular electric modes, comprising primarily the TE_{01} mode and secondarily spurious higher order modes enter at one end of guide section 10, and propagate therealong until vanes 11 are encountered. Upon reaching vanes 11, the magnetic field associated with the propagating energy induces currents in the metallic vanes. Since the energy distributions associated with each mode are different, their effects when incident on the conductive vanes are different. It has been found that the radial current density in the vanes associated with the TE_{01} mode is substantially zero at a location which is 0.628 times the radius of the supporting guide,

while all other circular electric wave modes are characterized by a non-zero radial current density at this location. Thus if a gap filled with resistance material is properly introduced into vanes 11 of FIG. 1, a mode selective phenomenon will occur. When the resistance gap is located a radial distance equal to 0.628 of the total radius of the supporting guide, the TE_{01} mode will propagate through the mode filter substantially unaffected by the resistance gap while the spurious higher order modes will be attenuated. The length of the mode selective vanes is preferably of the order of several wavelengths of the propagating energy, in order that substantially all wave power in the higher order circular electric wave modes present in the incident energy will be dissipated and TE_{01} wave power free of spurious circular electric wave modes will emerge from the filter.

FIG. 3 is a transverse cross sectional view of another embodiment of the present invention. In FIG. 3 guide section 40 of circular transverse cross section contains within its cross section four predominantly metallic segments 41. Each of segments 41 contains a gap 42 loaded with electrically lossy resistive material midway between its extremities. The dimensions and electrical characteristics of segments 41 and gap 42 are similar to those set out hereinabove with respect to the embodiment of FIG. 1 except that the total radial extent of segments 41 is less than that of the previously described vanes. In particular the metallic loading portions of FIG. 3 in which currents are induced by the propagating waves are confined to regions immediately adjacent the region of zero longitudinal magnetic field for the desired mode of propagation. In this manner the total amount of conductive loading with its attendant reflection problems may be minimized. As seen in FIG. 3 the transverse extremities of each of the segments 41 are tapered for the purpose of minimizing edge effects caused by the introduction of conductive metal solely in regions of relatively high TE_{01} mode field intensity. The entire array of segments 41 is supported within guide 40 by means of dielectric filler 43 which may comprise polyfoam or other material of low dielectric constant. The resistance material is of course positioned at the critical radius r_1 , the exact value of which depends upon the desired mode of transmission. For a particular desired mode, r_1 is determined by the zero of the Bessel function of zero order which as set out above describes the radial variation of the longitudinal magnetic field distribution of that mode.

FIG. 4 is a perspective view of a mode filter for use in a circular electric mode transmission system in which both circular magnetic and noncircular modes as well as circular electric modes other than the desired mode are present. The principal guiding medium comprises helix guide 51 within the cross section of which is positioned a resistance gap filter 52 in accordance with the invention. Helix guide 51 comprises helically wound conductor 53 surrounded by lossy jacket 54 which is in turn surrounded by conductive jacket 55. As is now well known in this art propagating modes of the circular electric family are characterized by the absence of longitudinally directed induced wall currents whereas modes of the asymmetric and circular magnetic variety are in general characterized by such currents. Thus any asymmetric or circular magnetic mode propagating within helix guide 51 will suffer attenuation in the lossy material surrounding the helix while circular electric modes will propagate substantially unaffected. For a more complete description of the helix wave guide itself, reference may be had to United States Patent 2,848,696 issued August 19, 1958 to S. E. Miller. However, since power in higher order circular electric modes is also generally undesirable, provision for filtering these modes is necessary. Thus in FIG. 4 conductive radial vanes 56 including gaps 57 containing electrically lossy material are disposed within the cross section of the helical winding 53. As set out in detail hereinabove the resistance gaps are

disposed at a location for which no radially directed currents are induced in the vane by the desired mode of propagation. In this manner all wave modes of the circular electric family other than the desired mode will be attenuated. The mode filter of FIG. 4 is thus a filter which affects all noncircular modes and all circular modes except the one desired propagation mode. It is to be understood of course that other types of asymmetric mode filtering wave guides, such as for example the lossy jacketed spaced conductive ring guide illustrated in United States Patent 2,649,578 issued August 18, 1953 to W. J. Albersheim, may be substituted for the illustrated helix guide and that the tapered segment embodiment of the circular mode filters shown in FIG. 3 of the present disclosure may be substituted for the illustrated vanes.

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

What is claimed is:

1. A mode filter for all but a selected one of the modes of the circular electric mode family comprising a section of hollow conductively bounded wave guide having a circular transverse cross section with an inside radius r sufficiently large to support a plurality of said modes within a given range of operating frequencies, each of said modes being characterized by longitudinal magnetic field components, a plurality of conductive metallic members extending radially within said guide in the path of said longitudinal components, said members having a transverse thickness greater than twice the skin depth of penetration of said components into said members whereby radially directed electric currents are induced in said members by said components, and means for selectively dissipating certain of said currents comprising a region of electrically lossy material filling a longitudinally extending gap in each of said members, said gap being radially positioned at that location for which the longitudinal magnetic field components of said selected mode are minimum.

2. In combination, a section of bounded hollow pipe wave guide of circular transverse cross section having a longitudinal axis and adapted to propagate a plurality of circular electric wave modes within a given operating range of frequencies, and means for selectively attenuating power in all but one of said plurality of modes, said means comprising at least one conductive metallic member extending radially within said guide in the region between said axis and said boundary, each such member having a gap therein which is filled with material adapted to dissipate electric currents, the thickness of said members in a circumferential direction being greater than twice the skin depth of penetration of said modes into said dissipative material.

3. The combination according to claim 2 in which the location of said gap coincides with the location at which the value of the zero order Bessel function describing the radial variation of the longitudinal magnetic field distribution of one selected mode of said plurality of modes is equal to zero.

4. The combination according to claim 2 in which said conductive member comprises a vane extending from said axis to said boundary.

5. The combination according to claim 2 in which said conductive member comprises a segment of quasi-ovoid transverse cross section extending only a portion of the distance between said axis and said boundary.

6. A mode filter comprising a section of hollow wave guide of circular transverse cross section supportive of a plurality of circular electric modes within a given range of operating frequencies, and means for selectively

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attenuating all except one of said modes, said means comprising at least one vane of conductive metallic material disposed within said guide and extending radially between the longitudinal axis and the inner surface of the boundary wall of said guide, each said vane containing a longitudinally extending gap at a specified radius r_1 from said axis, said gap being filled with material adapted to dissipate electric currents, each said vane having a circumferential thickness greater than twice the skin depth of penetration of said modes into said dissipative material.

7. The mode filter according to claim 6 in which said radius r_1 places said gap at the region in which the longitudinally extending magnetic field components of the desired mode of transmission within the circular electric family are at a minimum.

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