

May 18, 1965

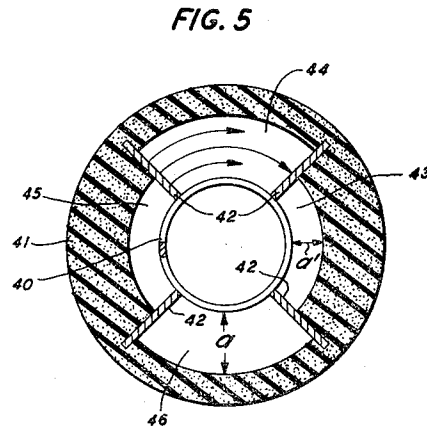
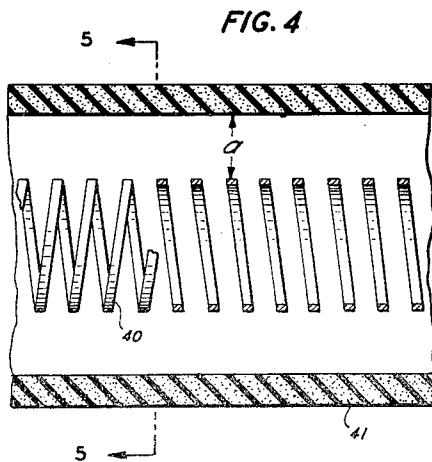
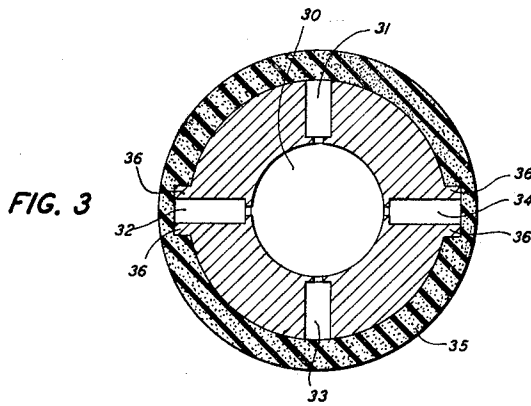
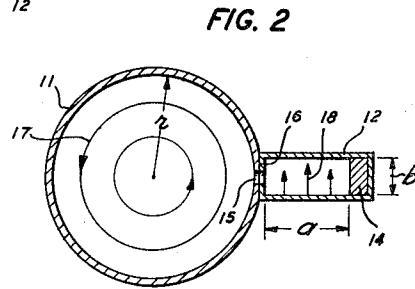
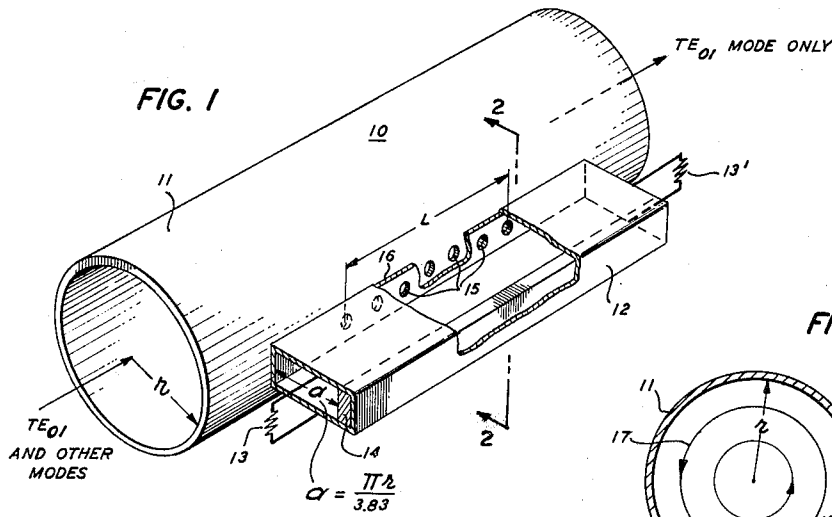
HANS-GEORG UNGER

3,184,695

CIRCULAR ELECTRIC MODE FILTER

Filed Nov. 1, 1960

2 Sheets-Sheet 1



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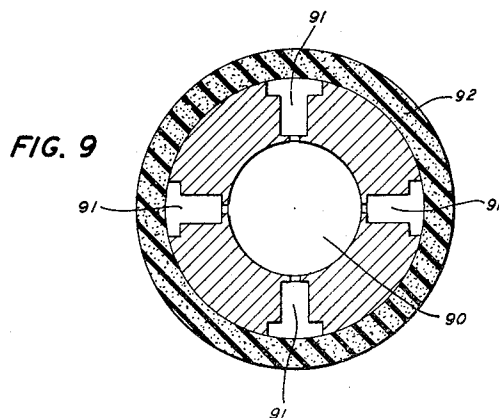
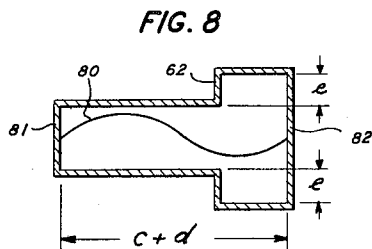
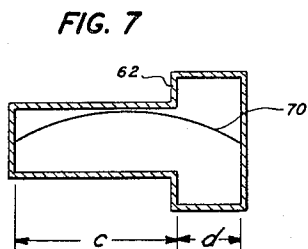
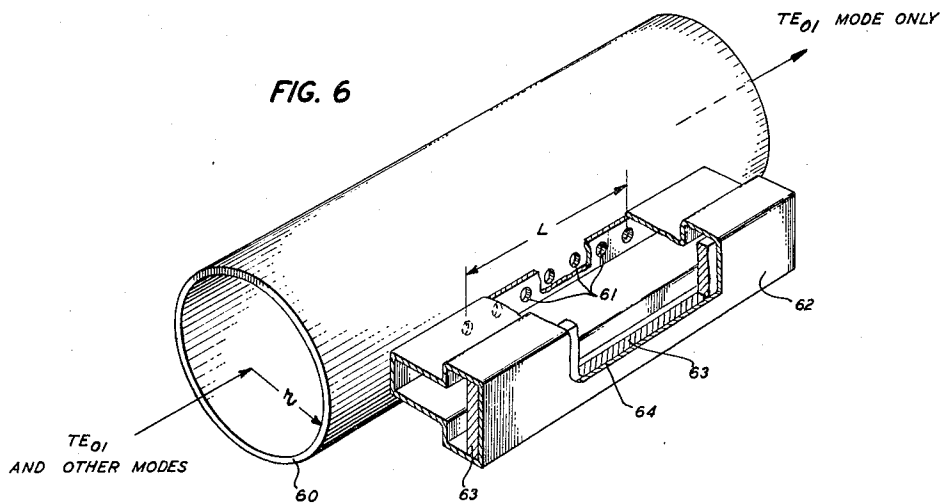
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CIRCULAR ELECTRIC MODE FILTER

3,184,695

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2 Sheets-Sheet 2



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3,184,695

CIRCULAR ELECTRIC MODE FILTER

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6 Claims. (Cl. 333-93)

This invention relates to the transmission of electromagnetic wave energy along multimode transmission lines and, more particularly, to filtering devices having transmission characteristics dependent upon the particular modes of transmission of said energy.

Guided electromagnetic waves are capable of transmission in a very large number of forms or modes, each mode being distinguished and identified by the characteristic configuration of its component electric and magnetic fields. For example, in a rectangular wave guide the designation TE_{10} represents a wave having a one-half period variation in the electric field across the width of the guide and, since the field is uniform, no electric field variation across the height of the guide. This mode configuration is commonly designated the dominant mode in rectangular guide. Likewise, in a round wave guide, the designation TE_{01} represents a wave having a wholly tangential electric field forming a series of circles concentric with the guide axis with no variation in the electric field in a circumferential direction but with a one-half period variation in the radial direction. Such a wave is commonly known as the circular electric wave. By virtue of the characteristic differences among the modes, one mode may be rendered particularly suitable for a given application in electrical communication systems while a different mode may be most particularly suited for some other application.

It is well known in the microwave transmission art that the circular electric mode, when propagated in a circular metallic pipe, experiences decreasing attenuation as the frequency is increased. Accordingly, such mode is particularly adapted to, and finds wide application in, long distance wave guide transmission systems, as described by S. E. Miller in an article entitled "Waveguide as a Communication Medium," volume 33, Bell System Technical Journal, 1954, at pages 1209-1265. In general however, the pipe chosen for transmitting the circular electric waves has a radius from two to fifteen times the cutoff radius at the lowest transmission frequency. Thus, the typical circular electric mode guide is multimode in nature; that is, a plurality of modal configurations other than the circular electric mode may be generated in the guide and may 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 the generation of spurious modes 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

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along the transmission path periodically to reduce the power level of the unwanted modes.

In the past, these means have frequently taken the form of attenuating mechanisms inserted within the main transmission path. Oftentimes such devices undesirably disturb and attenuate energy in the desired mode. Alternatively, the filtering means have taken the form of couplers in which energy of unwanted modes is coupled into an auxiliary transmission path wherein it is dissipated in a resistive termination.

It is well known that when the propagation constants associated with each one of a given pair of modes in coupled guides are equal, complete power transfer at a single frequency occurs. In long distance wave guide communication systems, however, wideband signals are transmitted, and it is desirable that power in unwanted wave modes be coupled over a wide frequency band into a single auxiliary guide.

It is therefore an object of the present invention to couple wave energy in the form of unwanted mode configurations at the operating frequencies from a main transmission path into an auxiliary line with substantial independence of frequency.

It is a more specific object of the invention to couple specific unwanted modes, at the operating frequencies from a main transmission path into an auxiliary guide which includes an attenuating mechanism which is distributed along the coupling region.

Oftentimes, from considerations of cost and space conservation, it may be undesirable to provide a separate coupling interval and auxiliary guide for each undesired mode within the main guide.

It is therefore a further object of the invention simultaneously to couple energy with substantial independence of frequency over the operating range in a plurality of unwanted wave modes from a main transmission path into a single lossy auxiliary transmission path.

In accordance with the present invention, the real part of the propagation constant of the auxiliary guide in the region of coupling is made greater than the same quantity in the main guide. Additionally, the imaginary parts of these propagation constants are equated. When the real part of the propagation constant, i.e., the attenuation constant, is sufficiently increased and when the electrically lossy material is properly placed within the auxiliary guide, broadband coupling of one or more specified unwanted modes from the main guide into the auxiliary guide occurs.

In a first embodiment of the invention, a multimode guide of circular transverse cross section is coupled to a guide of rectangular transverse cross section through a plurality of apertures in the common guide wall. The rectangular guide is physically proportioned to have a dominant mode cutoff frequency equal to the cutoff frequency of a selected unwanted mode in the circular guide. Electrically lossy material effectively forms one boundary of the auxiliary guide in the region of coupling, and is positioned to insure that the wall currents extending within the material are directed transverse to the direction of energy propagation. In general, the slab is located opposite the coupling holes, and either abuts the wall of the auxiliary guide or itself forms that wall. By thus positioning the lossy material, its attenuation characteristic as a function of frequency may be made substantially congruent with the coupling characteristic of the coupling array as a function of frequency, thereby causing the mode filtering characteristics of the coupler to be substantially frequency insensitive over a wide frequency band.

In a second embodiment of the invention, the main transmission line takes the form of a helically wound conductor. A surrounding cylinder of lossy material is

spaced away from the helix, with longitudinal conductive vanes extending radially outward from the surface of the helix, thereby dividing the resulting chamber into a plurality of semirectangular guides supportive of hollow pipe wave modes.

In a third embodiment of the invention the auxiliary guide takes the form of a hollow T-shaped guide which is coupled through a plurality of apertures in the wall forming the bottom of the stem of the T to a round multimode main guide. Lossy material either forms or abuts the top wall of the cross member of the T. By virtue of the special shape of the auxiliary guide wave energy propagating in two different wave modes in the main guide may be broadband coupled into and dissipated in the auxiliary guide.

The above and other objects, the nature of the present invention, and its various features and advantages 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 perspective view of a first mode filtering coupler in accordance with the invention;

FIG. 2 is a transverse cross sectional view of the coupler of FIG. 1;

FIG. 3 is a transverse cross sectional view of a plural channel coupler patterned after the filter of FIG. 1;

FIGS. 4 and 5 are longitudinal and transverse cross sectional views, respectively, of a helical type mode filter in accordance with the invention;

FIG. 6 is a perspective view of a T-guide mode filtering coupler in accordance with the invention;

FIGS. 7 and 8 are transverse cross sectional views of a T-guide showing the electric field distribution of several modes therein; and

FIG. 9 is a transverse cross sectional view of a variation of the coupler of FIG. 6.

Referring more particularly to FIG. 1, there is shown, in accordance with the present invention, a partially broken away perspective view of a mode filter 10 for selectively filtering wave energy in the TE₀₂ wave mode from a circular wave guide and dissipating it as TE₁₀ mode wave energy in a dominant mode rectangular wave guide. The filter of FIG. 1 comprises a first section of guide of circular transverse cross section 11 which is a multimode guide having an inside radius *r*. The terminal ends of guide 11 are adapted by means not illustrated for connection to other similar wave guide sections, one of which may be a transmitter or other source of circular electric waves, the other of which may be a receiver or other utilizer of such waves. Located adjacent guide 11 and contiguous with a portion of the length thereof is a second section 12 of wave guide of rectangular transverse cross section which, as shown in FIG. 2, is a dominant mode guide having an effective wider transverse dimension *a* and a narrower transverse dimension *b*. The terminal ends of guide 12 are terminated in a reflectionless manner by their characteristic impedance as indicated by absorptive terminations 13, 13'. Extending longitudinally along one side of the guiding path provided by guide 12 is rectangular slab 14 of electrically lossy material. By the term "electrically lossy" it is intended to mean that the material is capable of converting substantial amounts of electric currents which flow therein into heat energy. As a typical example, slab 14 may comprise pressed carbon, or carbon-loaded plastics.

Guides 11 and 12 are coupled along their contiguous portions by equally sized and equally spaced apertures 15 which extend through the narrow side wall 16 of rectangular guide 12 and through the adjacent portion of guide 11. Coupling apertures 15 are distributed along a distance *L*, a substantial portion of the length of guide section 12 and lossy slab 14. These coupling apertures are illustrated as circular, but they may be of any shape,

such as elliptical, consistent with good coupling considerations.

The relative cross sectional dimensions of transmission paths 11 and 12 are chosen such that the phase constant of a particular unwanted mode in guide 11 is equal to the phase constant of the dominant TE₁₀ mode in guide 12. Such an equality of phase constants is reflected in an equality of cutoff wavelength for the particular mode pair selected. It is known that if the cutoff wavelength for a particular mode in each of two guides is made equal, the phase constant of wave energy in the two guides will be equal, regardless of the particular frequency of the energy. These considerations are fully discussed in any standard textbook on wave guide transmission such as G. C. Southworth's Principles and Applications of Waveguide Transmission, D. Van Nostrand, 1950.

Furthermore, the cutoff wavelength in a rectangular guide for any TE_{*m**n*} or TM_{*m**n*} wave mode depends upon the physical dimensions of the guiding path and may be expressed

$$\lambda_c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$$

Thus, for the TE₁₀ mode, the cutoff wavelength is equal to 2*a*.

In circular wave guides, the cutoff wavelength for a particular mode is determined by the radius *r* of the guide and is expressed as

$$\lambda_c = \frac{2\pi r}{k_{mn}}$$

in which *k_{mn}* is the Bessel function constant for the particular mode of interest. A complete discussion of the Bessel function and its derivation may be found in any standard text on wave guide transmission, and it will suffice here to give the values for *k_{mn}* for several lower order wave modes.

For transverse magnetic waves,

<i>k</i> ₀₁ =2.40	<i>k</i> ₀₂ =5.52	<i>k</i> ₀₃ =8.65
<i>k</i> ₁₁ =3.83	<i>k</i> ₁₂ =7.02	<i>k</i> ₁₃ =10.17
<i>k</i> ₂₁ =5.14	<i>k</i> ₂₂ =8.42	<i>k</i> ₂₃ =11.62

For transverse electric waves,

<i>k</i> ₀₁ =3.83	<i>k</i> ₀₂ =7.02	<i>k</i> ₀₃ =10.17
<i>k</i> ₁₁ =1.84	<i>k</i> ₁₂ =5.33	<i>k</i> ₁₃ =8.54
<i>k</i> ₂₁ =3.05	<i>k</i> ₂₂ =6.71	<i>k</i> ₂₃ =9.97

Thus, for the TE₀₂ wave,

$$\lambda_c = \frac{2\pi r}{7.02}$$

In order then that the TE₁₀ wave mode in guide 12 have the same cutoff wavelength, and therefore the same phase constant as the TE₀₂ wave mode in guide 11, the cutoff dimension *a* must be equal $\pi r/7.02$, and this particular proportion of the guides 11, 12 is indicated on FIG. 1. It should be noted that dimension *a* is measured from coupling holes 15 to the surface of lossy slab 14. This is required since it is slab 14 which forms the effective wall of the transmission path provided by guide 12. In accordance with the usual practice for rectangular wave guide cross sections, the dimension *b* of guide 12 may be equal to approximately one-half of dimension *a* or $\pi r/7.66$.

Having thus proportioned the transmission paths, it would be expected that energy in the TE₀₂ mode appearing in guide 11 will, for a particular frequency at least, be completely coupled into guide 12 in the form of TE₁₀ waves. However, one object of the present invention is to provide, for any particular coupling length *L*, complete coupling of the TE₂₀ mode over a band of frequencies of the order of 100 percent of the midband frequency. Thus, for example for a midband of 60 kilomegacycles, the coupling should extend over a 60-kilomegacycle band, from 30 kilomegacycles to 90 kilomegacycles. It is to-

ward this aim that the particular characteristics of lossy slab 14 are of paramount importance. As partially illustrated in FIG. 2, the electric field configuration of the TE_{02} wave mode in guide 11 comprises a series of concentric circles 17 whereas the magnetic field of the same mode has both transverse and longitudinal components. The longitudinal magnetic components extend through coupling apertures 16 into guide 12 in which they set up traveling electromagnetic waves whose magnetic field configuration is compatible with that of the coupling field. This mode is the dominant TE_{10} mode whose electric field is represented by the transverse arrows 18 and whose magnetic field comprises loops lying in planes parallel to the board guide walls, with longitudinal portions extending past apertures 16. Thus, it is evident that the magnetic coupling which takes place is proportional to the strength of the magnetic field of the coupling wave. In order to realize broadband mode filtering in accordance with the present invention it is desirable that the frequency dependence of the rate of energy attenuation in guide 12 be substantially identical to the frequency dependence of the rate of energy coupling, or coefficient of coupling C, into guide 12. This may be assured by so positioning the lossy material of slab 14 to be in the presence of mode currents which are themselves dependent upon the coupling. In FIG. 1 slab 14 forms the effective narrow wall of guide 12 which is opposite the wall containing the coupling holes. As is well known, the narrow transverse walls of a rectangular guide supporting the TE_{10} wave energy mode carry currents induced therein by the component magnetic field of the propagating wave. Since the TE_{10} wave is symmetric with respect to a line passing through the center of the guide normal to its broad walls the intensity of the magnetic field components which induce currents in slab 14 are identical to the intensity of the magnetic field components coupled from guide 11. In fact these components are corresponding portions of a symmetric mode. Thus, the frequency dependence of attenuation will be identical with the frequency dependence of the coefficient of coupling if the lossy slab is positioned in a region in which solely transverse wall currents are generated since the intensity of the magnetic components which generate the transverse wall currents are identical with the intensity of the magnetic components producing coupling into the guide. With the lossy material thus properly located, the broadband character of the filter may be assured by the proper selection of the lossy properties of the slab. In this connection, it was been found that if the ratio of the attenuation constant of the lossy guide 12 over the coefficient of coupling C is approximately equal to 2, optimum mode filtering of a broadband character will be produced. In practice, however, the ratio may vary from 1 to 4.

It should be noted again that the particular length of the coupling interval selected is not itself critical in limiting the broadband nature of the device. As a minimum limit, for good filtering action, a total length of coupling interval of the order of several wavelengths of the energy coupled would be satisfactory. Additionally it should be emphasized that the lossy material should be placed in regions in which currents are induced by solely longitudinal magnetic field components (i.e., solely transverse currents in the lossy material). If the material forms the top and bottom walls of guide 12, for example, the frequency dependence of attenuation would be different from the frequency dependence of the coefficient of coupling, and the broadband nature of the device would be impaired.

In the operation of the mode filter shown in FIGS. 1 and 2, wave energy in the TE_{01} and other modes enters guide 11 from an excitation means connected thereto. When this energy reaches the region of coupling apertures 15, magnetic coupling into guide 12 occurs. By virtue of the relative proportions of the guides, TE_{01} wave power in guide 11 does not set up a traveling wave mode in

guide 12, whereas power in the TE_{02} mode, which has a phase constant in guide 11 equal to the phase constant of the TE_{10} mode in guide 12, induces the latter mode in the auxiliary guide. As propagation proceeds in guide 12, currents are both induced and attenuated in lossy slab 14. With the lossy material properly disposed within guide 12, broadband attenuation of the order of 15 decibels or more may be realized at the operating frequencies. This attenuation is suffered by the particular mode in guide 11 having a phase constant equal to the phase constant of the dominant mode in guide 12.

FIG. 3 is a transverse cross sectional view of another embodiment of the invention in which a plurality of unwanted wave modes propagating in a main transmission path may be eliminated. The main transmission path takes the form of conductively bounded wave transmission path 30. Spaced around guide 30 are auxiliary transmission paths 31, 32, 33, and 34. Auxiliary paths 31-34 have dimensions in a transverse direction normal to the boundary of guide 30 selected, in accordance with the principles set out above, such that the phase constant of a particular unwanted mode propagating in guide 30 is equal to the phase constant of the dominant mode wave propagating in the auxiliary guide. As illustrated in FIG. 3 guides 31 and 33 are similarly dimensioned and thus both couple the same mode from guide 30. Likewise, guides 32 and 34, while proportioned differently from guides 31, 33 by virtue of conductive lips 36, have equal cutoff dimensions and thus serve to couple and to dissipate a mode different from that coupled by guides 31, 33. Surrounding the entire assembly is lossy cylinder 35, which introduces attenuation by forming the fourth boundary wall of guides 31-34. The material of cylinder 35 is similar to that of element 14 in FIGS. 1 and 2, discussed above.

As illustrated in FIG. 3, guides 31-34 are formed as recesses in the conductive wall of guide 30. In general, at frequencies within the millimeter wave range such a structure presents few fabricating problems and, by virtue of its compact simplicity, is extremely attractive. However, at lower frequencies, it would be inconvenient to utilize a main transmission path having a radial wall thickness of the order of one-half wavelength at the operating frequencies. In the lower frequency ranges, therefore, a plurality of separate wave guides, as illustrated in FIG. 1 would be spaced around the periphery of a single main transmission path.

The number of longitudinally coextensive auxiliary wave channels possible in such a filter embodiment is not intended to be limited to four as illustrated in FIG. 3. In a particular mode filter built and tested, a total of 10 such channels were provided around the periphery of a single main guide.

FIGS. 4 and 5 are longitudinal and cross sectional views of a helix mode filter structure in accordance with the present invention. The main transmission path is formed by helix 40 which itself comprises a spirally wound metallic ribbon with adjacent turns spaced apart less than one-quarter wavelength of the highest frequency propagating within the helix. Spaced away from helix 40 by a preselected distance is cylindrically shaped member 41 of electrically lossy material. As seen in FIG. 5, which is a transverse cross sectional view of the guide of FIG. 4 taken at line 5-5, the cylindrical region between helix 40 and lossy element 41 is divided by means of radially extending conductive septa 42 into four separate regions or channels 43, 44, 45, 46. Each of these latter channels serves as a separate wave guide supportive of a quasi-rectangular mode. The circular electric mode within helix 40 is characterized by magnetic vector components which extend longitudinally along the helical boundary, and thus magnetic coupling through the helix will tend to set up modes within guides 43-46 with similar longitudinally extending magnetic vector components. With magnetic vectors extending along helix 40 forming part of a magnetic loop, it is readily seen that the electric vectors for a

dominant mode wave in the auxiliary guides extend normal to septa 42, as illustrated in guide 44.

Thus, for the TE₁₀ type waves in guides 43-46, the radial dimension, labeled a in guide 46 and a' in guide 43, is the cutoff determining dimension. By properly selecting this dimension in accordance with the principles set out above in connection with the filter of FIGS. 1 and 2, unwanted modes propagating within helix 40 may be coupled into guides 43-46 over a broad frequency band and dissipated in lossy member 41. As illustrated in FIG. 5, guides 43 and 45 have cutoff frequencies equal to each other, as do guides 44 and 46. Again, as was the case with respect to FIG. 3, the number of channels is not limited to four, as shown, but may be any number consistent with the space available.

FIG. 6 is a perspective view, partially broken away, of another mode filter in accordance with the present invention. An important feature of the embodiment of FIG. 6 is that power in a plurality of unwanted mode configurations propagating in the main transmission path may be simultaneously coupled into and attenuated in a single auxiliary wave guide.

In FIG. 6 the main transmission path comprising guide 60 of circular transverse cross section, is coupled through apertures 61 to auxiliary guide 62. Coupling apertures 61 are characterized and distributed over a length L in a fashion similar to that described above in connection with FIG. 1. Auxiliary guide 62 is conductively bounded as illustrated and is of T-shaped transverse cross section. Extending along the broadest wall of T-guide 62, and in a location of maximum displacement from coupling apertures 61 is slab 63 of electrically lossy material. As stated above, slab 63 is characterized by attenuating properties which serve to dissipate electric currents induced therein by energy propagating in the T-guide. The thickness of slab 63 in a direction normal to the broad wall against which it rests in FIG. 6 should be greater than the skin depth of penetration of the propagating waves. Thus, slab 63 itself forms the effective broad wall of the transmission path provided by T-guide 62 and, if desired, the broad conductive wall 64 may be omitted. T-guide 62 and slab 63 are proportioned such that the cutoff wavelengths of the dominant and first higher order mode therein are equal to the cutoff wavelengths respectively of two higher order circular electric modes in main guide 60. The physical implications of these conditions may be more easily understood by reference to FIGS. 7 and 8, which are transverse cross sectional views of a T-guide supporting its dominant mode in FIG. 7 and the next higher order mode in FIG. 8.

In FIG. 7 the electric vector intensity distribution across the width of guide 62 is illustrated for the lowest order mode as single arc 70. This mode is seen to be similar to the dominant mode field distribution in ordinary rectangular guide. Dimensions c, d are selected such that the cutoff wavelength for the dominant mode in T-guide, $\lambda_{T1_{co}}$, is equal to, for example, the cutoff wavelength of the TE₀₂ mode in the main transmission path $\lambda_{M2_{co}}$ which, for a round pipe of radius r , is equal to

$$\frac{2\pi}{7.016}r$$

The second order mode in T-guide is illustrated in FIG. 8 by sinusoid 80 extending across guide 62. As seen from the illustration, the electric vector intensity passes once through zero between the transverse sides 81, 82. The dimensions of the cross member of T-guide 62, illustrated as e in FIG. 8, are selected such that, together with dimensions c and d , the cutoff wavelength of the second order mode in T-guide, $\lambda_{T2_{co}}$, is equal to, for example, the cutoff wavelength of the TE₃₀ mode in the main transmission path, which, for the round guide of radius r shown in FIG. 6 is equal to

$$\frac{2\pi}{10.17}r$$

The exact relative proportions among dimensions c, d , and e are best determined empirically, starting from the considerations set out above.

In the operation of the mode filter illustrated in FIG. 6, energy in the TE₀₁ and other wave modes enters main transmission path 60 at the left end as shown in FIG. 6. As the energy encounters the region of coupling holes 61, magnetic coupling of the two higher order modes for which T-guide 62 is proportioned occurs and propagating modes are set up in the T-guide. Since lossy material 63 forms the effective distant wall of the guide 62, the rate of attenuation in and the rate of coupling of energy into guide 62 are equal. The coupling in the presence of lossy material 63 is broadband and thus nearly all power in the selected higher order unwanted modes is dissipated. Substantially pure TE₀₁ wave energy exits guide 60 at its righthand terminal, as illustrated.

More efficient filtering per unit length may be afforded by using the structure illustrated in transverse cross section in FIG. 9. In FIG. 9 a main transmission path 90 is surrounded by a plurality of T-shaped auxiliary guides 91. Each of guides 91 is coupled via a plurality of coupling apertures to main guide 90. Surrounding the entire structure, and forming the radially outermost wall of each of guides 91 is lossy cylinder 92, comprising electrically lossy material similar to that described above. By properly proportioning guides 91, either identically or differently, energy propagating as unwanted modes in main guide 90 may be coupled into guides 91 and dissipated in cylinder 92. As disclosed above with respect to FIG. 6, each of guides 91 simultaneously broadband couples energy in two different modes from guide 90.

In all cases, it is understood that the above-described arrangements are illustrative of a small number of the many specific embodiments which can represent applications of the principles of this 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. In combination, a first transmission path capable of supporting electromagnetic wave energy in a plurality of circular electric wave modes within the desired range of operating frequencies, the phase constant of a selected one of said wave modes in said first path being β_1 , a second transmission path capable of supporting wave energy within said operating range in a preselected noncircular mode also with a phase constant β_1 extending longitudinally coextensive with a portion of said first path, means including spaced apertures for coupling wave energy propagating in said first path as said selected circular electric wave mode into said second path as said preselected noncircular mode, said coupling means having a coefficient of coupling C with a given amplitude versus frequency characteristic, and means including electrically lossy material for attenuating wave energy propagating in said second path, said lossy material forming the effective boundary of said second transmission path which is transversely opposite said coupling means, said lossy material effecting an attenuation constant α in said path having a frequency characteristic producing a ratio of attenuation constant α over coupling coefficient C approximately equal to 2 over said operating range.

2. The combination according to claim 1 in which said second transmission path comprises a hollow pipe guide of T-shaped transverse cross section and said spaced apertures are in the base of the stem of said guide.

3. A mode filter according to claim 1 in which said second transmission path comprises one of a plurality of auxiliary wave paths comprising wave channels of T-shaped transverse cross section positioned about the periphery of said first transmission path.

4. The combination according to claim 1 in which said first transmission path comprises a section of circularly

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wound helix waveguide and said second transmission path comprises one of a plurality of semi-rectangular volumes between longitudinally extending conductive vanes radially extending from the outer surface of said helix.

5 5. A mode filter for electromagnetic wave energy propagating within a given operating range of frequencies as modes of the circular electric family comprising a first shielded transmission path of circular transverse cross section having a radius r , said path being adapted to support wave energy in plurality of propagation modes including a first mode, said path producing a phase constant β_1 for said first mode, a second transmission path extending adjacent said first path and coupled over a longitudinal length to said first path, said second path being of rectangular transverse cross section with a wider transverse dimension substantially equal to $\pi r/3.83$, said dimensions of said second path producing a phase constant β_2 for a selected mode of propagation therein substantially equal to β_1 within said given operating range, said first mode and said second mode being different modes of propagation, and electrically lossy material forming the effective boundary wall of said second transmission path, said wall extending longitudinally in a region transversely opposite said longitudinal length of coupling.

6. A circular electric mode filter comprising a first wave guide of circular transverse cross section capable

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of supporting a plurality of circular electric wave modes, a plurality of auxiliary wave energy transmission paths comprising wave channels of rectangular transverse cross section extending longitudinally around the periphery of said first guide, means coupling said first guide and said auxiliary transmission paths along their lengths, and a cylinder of electrically lossy material surrounding said auxiliary transmission paths and forming the radially outermost boundary wall thereof.

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