

Dec. 6, 1960

E. A. J. MARCATILI
WAVEGUIDE TRANSDUCER

2,963,663

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4 Sheets-Sheet 1

FIG. 1

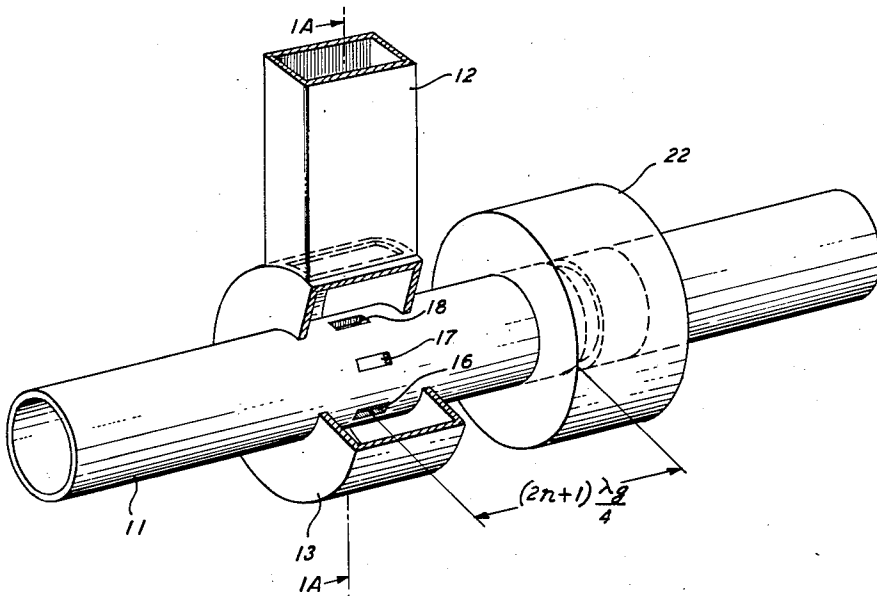


FIG. 1A

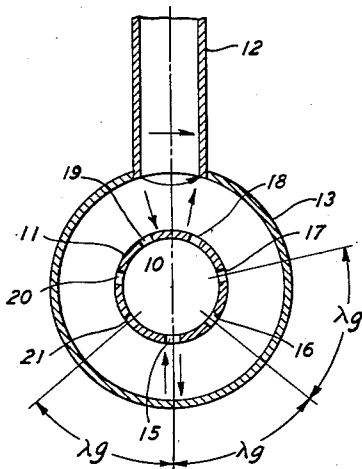
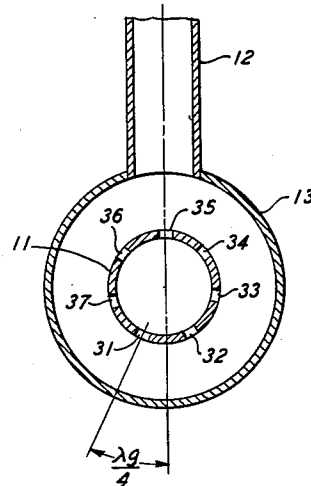


FIG. 3



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FIG. 2A

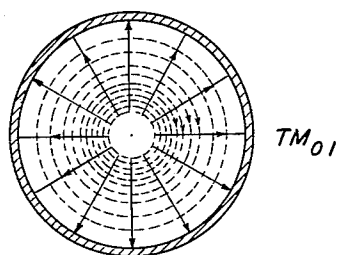


FIG. 2B

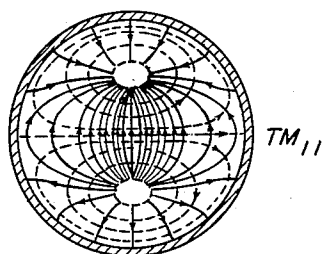


FIG. 2C

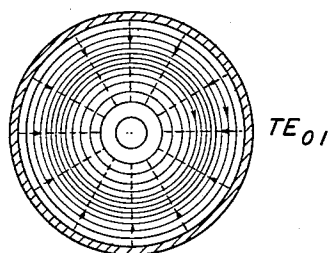
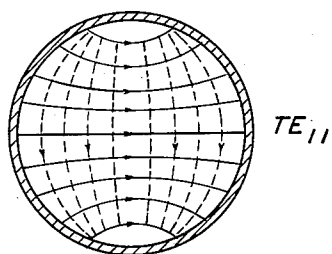


FIG. 2D



— LINES OF ELECTRICAL FORCE
- - - LINES OF MAGNETIC FORCE

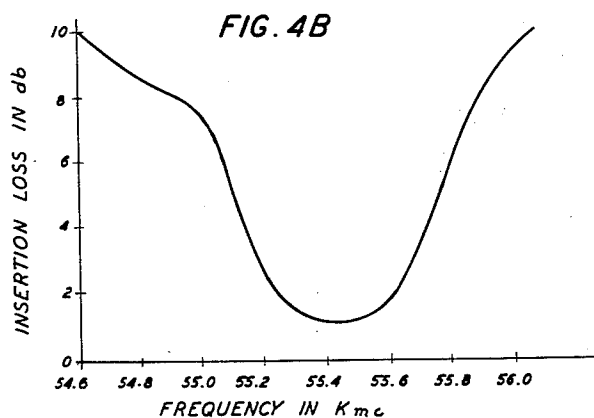
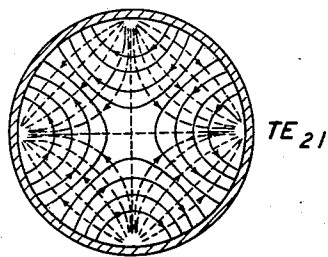


FIG. 2E



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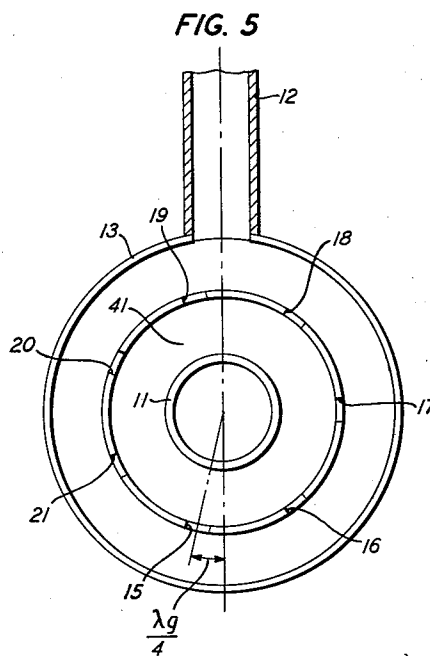
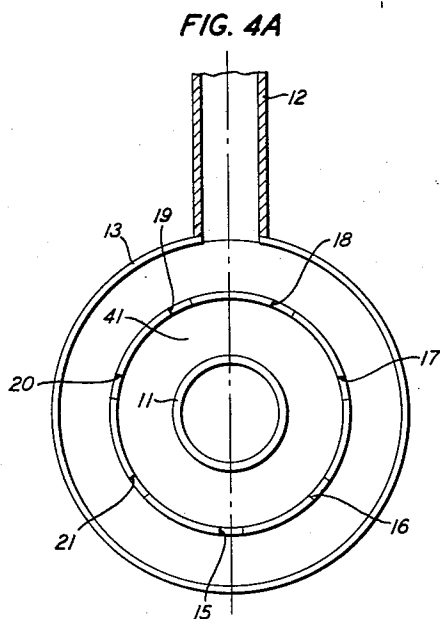
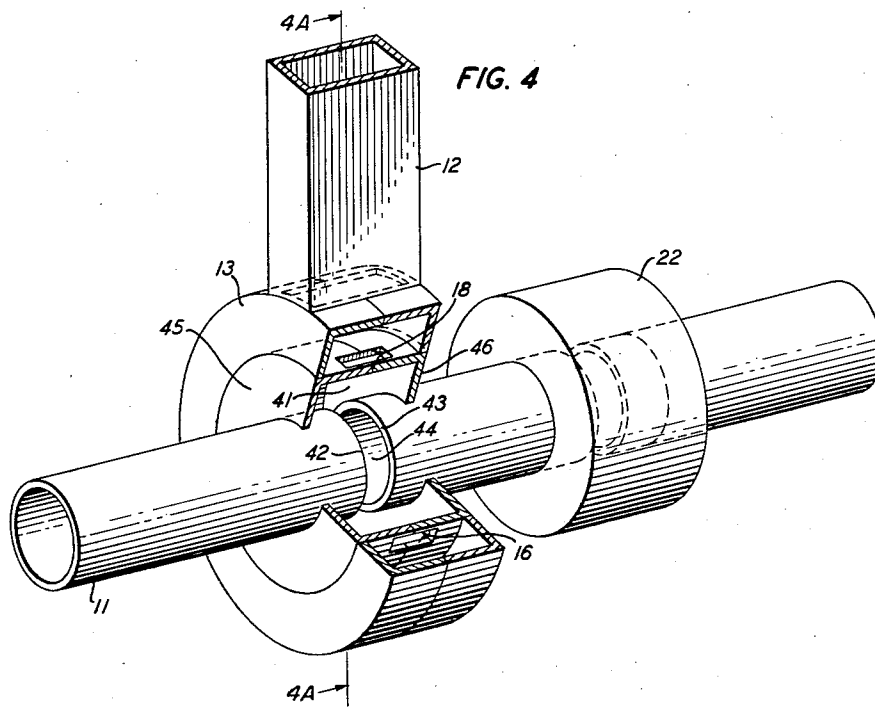
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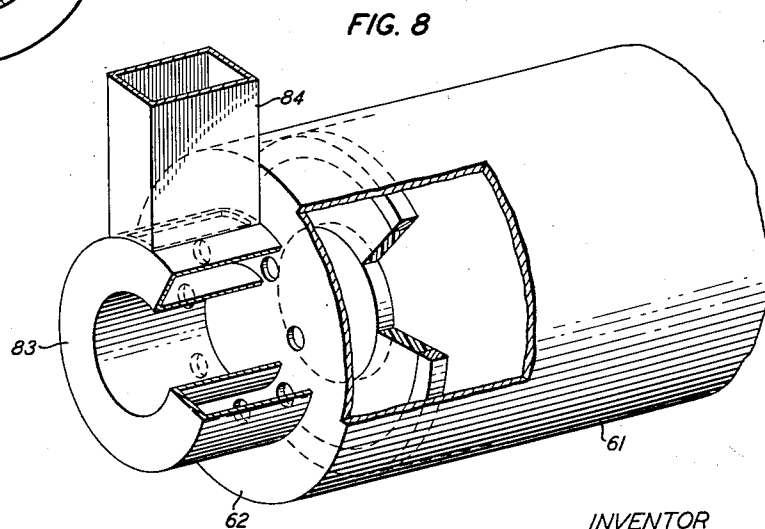
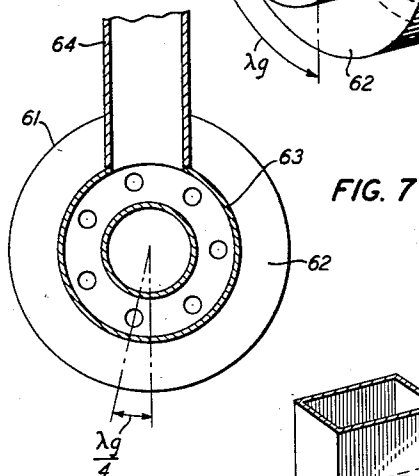
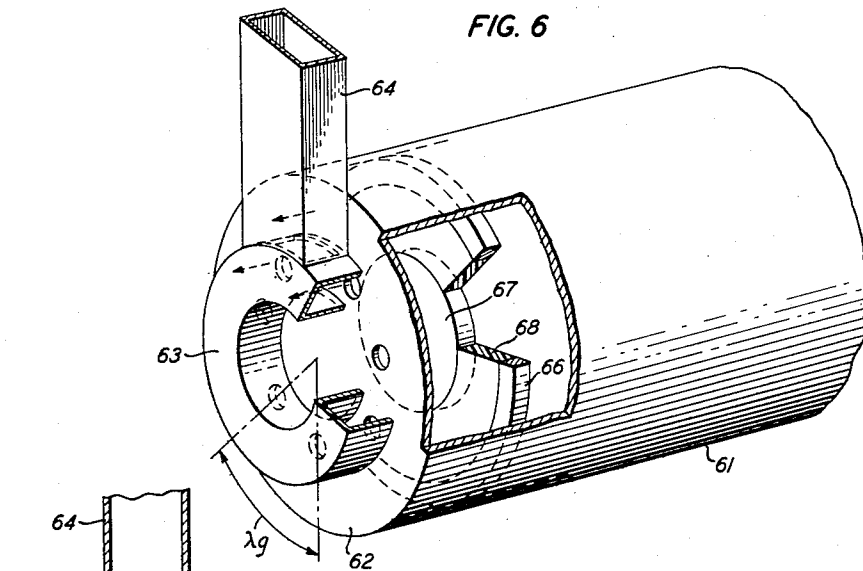
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WAVEGUIDE TRANSDUCER

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7 Claims. (Cl. 333—9)

This invention relates to electromagnetic wave guide transitions and more particularly to means for coupling between a wave guide of circular cross section and a wave guide of rectangular cross section on a highly selective basis with respect to mode configuration and frequency.

The upper limit of the usable portion of the radio-frequency spectrum is continually being raised in the effort to provide ever-increasing numbers of communication channels. The recognition that the circular electric mode propagating in circular metallic wave guides has a loss characteristic inversely proportional to frequency promises to substantially raise the frequency ceiling. As a consequence, the interest in circular wave guide theory and components has of late flourished considerably. The breakthrough in components development has, however, been quite uneven. It is still the case that many operations, for example, amplification, frequency mixing and the like are more effectively and efficiently performed in a rectangular wave guide system. As a consequence, means for efficiently interconnecting a rectangular wave guide and a circular wave guide operating in the circular symmetric modes are of great importance to the commercial development of circular wave guide systems. One critical problem in such a type of coupling is the undesired generation of spurious electromagnetic modes of wave energy propagation, i.e., the generation of a mode other than the sole mode for which that system of information propagation was specifically designed. The generation of such spurious modes constitutes a loss of efficiency and possibly information. Accordingly, in wave guide transitions (which perform mode conversion since the modes supported in rectangular guides are different from the modes supported in circular guides), freedom from any tendency to generate spurious modes is imperative.

Various rectangular to circular guide transition devices have been developed in the art with the view to insuring purity of the propagating mode in the circular guide. In the main, however, these structures have been either inefficient in insuring the purity of the generated mode or, if efficient, have been highly complicated physical structures.

It is, accordingly, the principal object of this invention to couple between solely one mode of wave energy propagation in a rectangular guide and solely one mode of wave energy propagation in a circular guide with a simple structural arrangement.

It is anticipated that the circular wave guide systems of the future will be multichannel devices of the frequency-division type. In such arrangements filters for dropping channels from the circular guide system are necessary so that the channels may be separately utilized or operated upon. Unfortunately, the prior art mode conversion devices are, in general, such complicated structures that propagation of wave energy in the circular guide must be terminated at the transition structure. Accordingly, these devices are inherently incapable of performing their mode conversion process simultaneously with channel filtering or dropping; in most cases the round guide must be terminated by a short circuit in the

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form of a metallic piston or plate at a critical distance from the guide transition in order to insure the purity of the mode generation. It is a particularly advantageous feature of this invention that the purity of the mode generated is maintained without disturbing the through characteristic of the circular guide, i.e., no short circuiting plates or pistons are required in the round guide to perform the mode conversion function, although if desired, the circular guide may be so terminated at the end of the system.

In accordance with the invention this object and the advantageous features discussed above are achieved by virtue of a special type of coupling arrangement which lends itself to the preservation of the purity of the modes converted and to simplicity in the structural arrangement, while at the same time being amenable to band pass filtering operations and applicable to a through transmission system. This coupling arrangement is such that a mode is generated in the circular guide solely by magnetic field or electric field excitation, but not both, from the rectangular guide; the excitation is provided through a multiplicity of apertures around the circumference of the circular guide symmetrically disposed to provide an in-phase synchronous excitation.

In one embodiment in accordance with the invention, a round wave guide has wrapped about it a rectangular guide curved into annular form such that one wide wall of the rectangular guide is common to a portion of the wall of the circular guide. Disposed in this common wall portion is a multiplicity of apertures extending around the circumference of the circular guide. Diametrically opposite to one of said apertures is located a rectangular guide, the end of which is coupled to the annular rectangular guide wrapped around the circular guide such that an E-plane T junction is formed by the straight rectangular guide and a portion of the annular rectangular guide. Wave energy which propagates in the dominant mode down the straight rectangular guide is divided into two equal portions propagating in opposite directions into the annulus, from the T junction. As a consequence of the E-plane junction, the electric field polarities of the two portions propagating in opposite circumferential directions around the annulus are 180 degrees out of phase. On reaching that part of the annulus diametrically opposite to the T junction, the two portions of wave energy meet out of phase and destructively interfere to form an electric field null. Furthermore, by virtue of this phase opposition, that point represents a virtual short circuit or reflecting plate such that the two portions of the wave energy are reflected back through the annulus in opposite directions from which they came, to form standing waves in the annulus. The location of the virtual short circuit and electric field null is precisely the location of one of the coupling apertures described above. Furthermore, each of the apertures around the circumference of the circular guide is spaced from the next succeeding aperture by one guide wavelength of the rectangular wave guide annulus. As a consequence, not only is that one aperture located at an electric field null but each of the multiplicity of apertures around the circumference of the circular guide is also located, of necessity, at an electric field null. Since it is the case that for standing waves the magnetic field intensity is at a maximum where the electric field intensity is at a minimum, the only type of coupling between the rectangular guide annulus and the circular guide that is possible through the coupling apertures is due to the magnetic field components in the annulus. In addition, the circular guide is thus excited simultaneously and in phase around its circumference at many points. This type of excitation provides no possibility of ambiguity in the type of mode excited in the

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circular guide. Specifically, the circular electric TE_{01} mode will thus be excited in the round guide.

In another embodiment in accordance with the invention precisely the same arrangement as the one above obtains except that the coupling apertures are not located as indicated above but are moved one-quarter wavelength of the frequency supported in the rectangular guide from their former positions such that they are now located, not at electric field nulls in the standing wave, but rather at the magnetic field nulls thereof. As a consequence, magnetic field excitation of the circular wave guide is impossible and solely electric field excitation occurs. This type of synchronous symmetric electric field excitation serves to generate solely the circular magnetic TM_{01} mode in the round guide.

To further enhance the effect of these mode conversion embodiments and to further insure the purity of the mode generated in the circular guide, a cylindrical resonant cavity may be included between the annular rectangular wave guide and the circular wave guide. In this way the coupling apertures communicate between the annulus and the cavity while the cavity communicates with the circular guide by a gap in the circular guide in the middle of the cavity portion. This arrangement is equally applicable to magnetic or electric coupling. The resonant cavity is designed to be resonant for the circular electric mode, or the circular magnetic mode as the case may be, for the frequency band of interest, i.e., to be dropped. The resonant cavity in this way enhances the filtering effect by guaranteeing complete transmission of all the energy in the frequency band of interest while further precluding the generation of spurious modes by virtue of an additional damping effect between the circular guide and the rectangular guide.

As thus described, these embodiments would operate such that energy passing from the rectangular guide to the circular guide would divide into two portions in the circular guide and propagate in opposite directions. If it is desired to have the energy propagate in solely one direction down the circular guide, a band reflection filter may, in accordance with the invention, be located along the circular wave guide one-quarter wavelength of the circular wave guide frequency from the coupling apertures, or from the gap in the circular guide, as the case may be. In this way, all the energy will propagate down the circular guide from the transition section in the direction opposite from the band reflection filter. Frequencies other than the band under consideration will not see the band reflection filter.

In a situation where through transmission in the circular guide is not necessary or not desired and where it is accordingly desirable that the circular guide be terminated, embodiments in accordance with the invention, similar to those described above, are available by applying an annular rectangular wave guide to an end plate of the circular guide rather than wrapping it around the periphery of the circular guide. In this way the circular guide is excited through apertures in the end plate rather than in the circumferential wall of the pipe.

Other objects and certain features and advantages of the invention will become apparent during the course of the following detailed description of the specific illustrative embodiments of the invention shown in the accompanying drawings.

In the drawings:

Figs. 1 and 1A represent, in perspective and cross-sectional view, respectively, a mode transducer in accordance with the invention for converting between the dominant mode in a rectangular wave guide and the circular electric TE_{01} mode in a circular wave guide;

Figs. 2A through 2E are standard representations of a plurality of electromagnetic field configurations unique to various modes of wave energy propagation;

Fig. 3 represents a transverse cross-sectional view of a mode transducer in accordance with the invention for

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converting between the dominant mode in a rectangular wave guide and the circular magnetic TM_{01} mode in a circular wave guide;

Figs. 4 and 4A represent, in perspective and cross-sectional view, respectively, a channel dropping filter in accordance with the invention performing the same type of mode conversion as the transducer of Figs. 1 and 1A;

Fig. 4B is a graph of the insertion loss characteristic of the embodiment of Figs. 4 and 4A;

Fig. 5 is a transverse cross-sectional representation of a channel dropping filter in accordance with the invention performing the same type of mode conversion as the transducer of Fig. 3;

Fig. 6 is a channel dropping filter performing mode conversion between the dominant mode of rectangular guide and circular magnetic TM_{0n} mode in circular guide in an arrangement wherein the circular guide is terminated at the filter;

Fig. 7 is a channel dropping filter performing mode conversion between the dominant mode of rectangular guide and circular electric TE_{01} mode in circular guide in an arrangement wherein the circular guide is terminated at the filter; and

Fig. 8 is a modification of the embodiment of Fig. 6 in that the same type of mode conversion is performed but with an E-plane T junction instead of an H-plane T junction.

More specifically, Fig. 1 in perspective view, and Fig. 1A in cross section, disclose a round to circular wave guide transducer, given by way of example in accordance with the invention, for reciprocally converting between the circular electric TE_{01} mode in a round wave guide and the dominant TE_{10} mode in a rectangular wave guide. Wave guide 11 is of the hollow metallic conductive pipe type having a circular transverse cross section. Oriented perpendicularly to circular guide 11 is a rectangular guide 12 having wide and narrow side walls; guide 12 is also of the hollow metallic conductive pipe type but of rectangular cross section. Guide 12 is disposed such that the wide walls thereof are parallel to the longitudinal axis of guide 11. One end of guide 12 opens into an annularly shaped wave guide 13 of rectangular cross section which is wrapped around the circumference of guide 11 such that the wide walls of the annular guide 13 are parallel to the wide walls of rectangular guide 12 and the longitudinally extending axis of guide 11. Furthermore, the wide wall 14 forming the inside surface of annulus 13 is common to a circumferentially extending portion of the wall of guide 11. Wave guide 12 opens into annulus 13 to form an E-plane T-junction. The extension of the longitudinal axis of guide 12 through to the diametrically opposite point of the inner wall 14 of annulus 13 locates a point wherein a rectangularly shaped coupling aperture is disposed so as to permit communication between annulus 13 and guide 11. This is best seen in Fig. 1A. Rectangular aperture 15 has its wide dimension extending parallel to the longitudinal axis of guide 11 while its narrow dimension extends perpendicular thereto. A multiplicity of similar apertures 16 through 21, each spaced apart one guide wavelength of annulus 13 from the next succeeding aperture, are disposed in wide wall 14 of annulus 13 to form equally spaced symmetrically located coupling means around the circumference of circular guide 11. As disclosed, seven such apertures are represented. Located a distance, from the apertures, of an odd integral number of quarter wavelengths of the frequency band to be dropped from, on introduced into, circular guide 11, in a direction parallel to the axis of guide 11, is an anti-resonant cavity filter 22 proportioned to provide complete reflection for the frequency band of interest in guide 11. This filter, well known in the art, is of the hollow cylindrical type coaxial with guide 11 and is coupled thereto by a gap in guide 11.

The operation of the embodiment represented by Figs. 1 and 1A may now be properly comprehended. Consider

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a frequency band, to be introduced into guide 11, propagating down guide 12 toward annulus. On reaching the E-plane T junction this wave energy divides into two equal portions, with each portion propagating in an opposite direction from the other around annulus 13. By virtue of the action of the E-plane T junction, the polarities of the electric fields of the two portions of the wave energy are 180 degrees out of phase, as indicated by arrows 10. The two portions meet at the opposite side of the annulus at aperture 15. Since they are precisely out of phase, they will add destructively and consequently provide an electric field null in the region of aperture 15. Furthermore, this phase relationship effectively provides a virtual short circuit across annulus 13 at aperture 15 so that both halves of the energy are reflected back along the annulus in the respective directions from which they came, to set up standing waves. Since each of apertures 15 through 21 are spaced exactly a guide wavelength apart along the inside wall of annulus 13, it follows that electric field nulls will occur at these apertures. Since the dominant mode in a rectangular guide has a magnetic field component intensity maximum where the electric field component intensity is zero, it follows that the only type of coupling through the apertures of the annulus that is possible is magnetic coupling. Furthermore, the only magnetic components at these locations, as is well known from the TE_{10} mode configuration, are parallel to the wide dimension of the apertures and the longitudinal axis of guide 11. It may be seen, therefore, that at each of seven locations around the circumference of circular guide 11, corresponding to the coupling apertures 15 through 21, there will be excited magnetic field components extending parallel to the longitudinal axis of guide 11. The excitation is, of course, provided simultaneously and furthermore the polarity of the components excited through all the apertures is the same.

This type of coupling results in the generation in guide 11 of the circular electric TE_{01} mode. Figs. 2A through 2E show the mode configurations for the most common modes supportable in a round wave guide which is proportioned to efficiently support the TE_{01} circular electric mode. It may be seen by inspection that the field excitation provided by the embodiment of Fig. 1 will excite only the TE_{01} mode in a round guide.

With the TE_{01} mode thus excited, the energy in guide 11 would divide in half and travel in opposite directions therealong except for the fact that band reflection filter 22 serves to insure, in a manner well known in the art, that all of the energy will propagate to the left.

The operation of the embodiment of Figs. 1 and 1A for propagation commencing in the direction from rectangular guide 12 to circular guide 11 has thus been described. It is clear that on the basis of reciprocity, the operation of the embodiment in the reverse direction, i.e., from circular guide 11 to rectangular guide 12, is the same. Thus, energy propagating from left to right along guide 11 in the frequency band for which cavity 22 is anti-resonant will excite annulus 13 solely by the magnetic field components in guide 11 at the plurality of apertures 15 through 21.

Fig. 3 is a transverse cross-sectional view of a mode transducer which in most respects is similar to the embodiment of Fig. 1 except that it is arranged to excite the TM_{01} circular magnetic mode in the round guide 11 rather than the circular electric mode. The only difference in structure between the two embodiments may be seen by comparing Figs. 3 and 1A which are identical except that the apertures of Fig. 3 are located one-quarter guide wavelength of annulus 13 away from the apertures of the embodiment of Fig. 1. Thus, apertures 31 through 37 are displaced one-quarter guide wavelength in annulus 13 from the respective locations of apertures 15 through 21 in Fig. 1.

As a consequence, the apertures 31 through 37 are located at magnetic field nulls instead of electric field

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nulls in the standing wave. This means that the field components exciting circular guide 11 from annulus 13 are the electric field components. Since the dominant mode in the rectangular annulus will have electric field components solely in a direction parallel to the narrow walls of annulus 13, it may be seen that the electric field components excited in the circular guide 11 by the apertures will be radial components, excited at a multiplicity of locations around the circumference thereof. Reference to the mode configuration drawings of Figs. 2A through 2E will demonstrate that the only mode compatible with this type of excitation is the circular magnetic TM_{01} mode which is the only mode having radial electric components distributed around the entire circumference of the guide having the same polarity in a radial sense. Except for the difference in the type of mode excited by this structure, the operation of the embodiment of Fig. 3 is precisely the same as the operation of the embodiment of Fig. 1.

The embodiments of Figs. 1 and 3 have thus been demonstrated to be highly efficient mode transducers in the sense that the purity of the mode is preserved, i.e., no spurious modes may be generated. However, with respect to their frequency sensitivity, i.e., with respect to their efficiency as channel dropping filters, they can be improved upon in the manner now to be described in Figs. 4, 4A and 5.

The embodiment represented by Figs. 4 and 4A provides the same type of mode conversion as that of Figs. 1 and 1A, namely the circular electric mode is generated in the round guide. However, the efficiency of the structure of Figs. 4 and 4A as a channel dropping filter is greatly enhanced by virtue of the introduction of a hollow resonant cavity between annulus 13 and round guide 11. Except for the modifications required by the introduction of this resonant band pass filter, the structure of Figs. 4 and 4A is in all respects similar to that of Figs. 1 and 1A. It may be seen that in Figs. 4 and 4A the annulus 13, instead of being wrapped directly around circular guide 11, is instead wrapped around a hollow cylindrical cavity 41 whose longitudinally extending axis is colinear with the longitudinal axis of round guide 11. Thus, the apertures 15 through 21 serve to excite cavity 41 directly. Round guide 11, which is coaxial to and passes through resonant cavity 41 has a gap interrupting it midway along the longitudinal extent of cavity 41 such that guide 11 has two open ends 42 and 43 with a space 44 therebetween. Coupling between guide 11 and cavity 41 is thus accomplished by virtue of gap 44. The dimensions of cavity 41 are proportioned in manner well known in the art so as to be resonant for a specific frequency band in the TE_{011} mode, namely, the frequency band to be dropped from circular guide 11 into rectangular guide 12, or for the reverse direction to be introduced into guide 11. However, because of apertures 15 through 21 and gap 44, modifications in the precise dimensions of the resonant cavity are required. These modifications can be achieved, for example, by having the ends 45 and 46 of the cavity formed by movable plungers or pistons (not shown) to change the electrical characteristic of the cavity, i.e., the cavity may be tuned thereby on an empirical basis. Alternatively, and more sophisticatedly, the dimensions of the cavity may be proportioned in accordance with the Bethe "small hole coupling" theory so as to render the cavity resonant at precisely the desired frequency band for the TE_{011} mode therein.

In the operation of the embodiment of Figs. 4 and 4A it may be seen that the rectangular and circular guides do not excite each other directly; they are only mutually excitable through the intermediary of the resonant cavity 41. Nevertheless, the type of excitation provided by the apertures for wave energy in annulus 13 will be the same in the embodiment of Fig. 4 as in Fig. 1 except

that cavity 41 will be excited directly rather than guide 11. For the opposite direction of propagation, guide 11 will excite cavity 41 directly rather than annulus 13. Mode purity is thus preserved in similar manner. However, two major additional advantages are achieved by virtue of the utilization of the resonant cavity 41, as described. Firstly, cavity 41 being resonant at the frequency band of interest will serve to completely couple all of the energy in the frequency band to be dropped, because of its designed resonance at this frequency band. A highly efficient channel dropping filter is thus obtained. Secondly, cavity 41 is designed to be resonant at this frequency band for the mode of interest, namely the circular electric mode. As a consequence, any tendency at all to excite a mode other than the circular electric mode in passing from annulus 13 to guide 11, is completely damped out between the outside wall of cavity 41 and the coupling gap in guide 11. In addition, the inclusion of the resonant cavity 41 results in a decrease in heat losses in the walls of the transmission path because the circular symmetric modes provide a high intrinsic Q.

Fig. 4B is a graph of insertion loss versus frequency for the embodiment of Figs. 4 and 4A. It may be seen that an insertion loss of only one decibel resulted for a frequency band of about 500 megacycles centered at 55.4 kilomegacycles.

The embodiment in Fig. 5 is similar to that of Figs. 4 and 4A except that it is arranged to couple the circular magnetic TM_{01} mode into guide 11 rather than the circular electric TE_{01} mode. Thus Fig. 5 is modified by moving the apertures in annulus 13 one-quarter guide wavelength from their position in the embodiment of Figs. 4 and 4A (the same modification as was provided in Fig. 3 over Figs. 1 and 1A and for the same reason). Accordingly, the operation of the embodiment of Fig. 5 is the same as that of Fig. 4 except that the mode coupled to the circular guide is the TM_{01} mode.

In all of the embodiments of the invention thus far described, the round wave guide constitutes a through communication path such that frequencies other than those in the band to be filtered or dropped will continue propagating along wave guide 11 beyond the channel dropping, mode conversion structure. These passed frequencies will then be utilized elsewhere along the guide by other mode conversion devices proportioned for the appropriate frequency bands. If, however, it is desired to terminate guide 11 at the channel dropping filter, or if it is desired to utilize the invention at a location where the circular guide commences, it is not necessary to have the circular guide constitute a through path, and it may be terminated in the manner of the embodiments of the invention now to be described.

Fig. 6 represents a channel dropping filter and mode converter wherein conversion occurs between the dominant mode in a rectangular guide and the circular magnetic TM_{0n} mode in a round guide. In this arrangement, however, coupling from the rectangularly cross-sectioned annulus to the round guide does not occur along the circumference of the round guide but rather at the end or terminated portion thereof. Thus, circular guide 61 is terminated at one end by an end closure, a metallic conductive plate 62. Annular guide 63 is mounted flush against the end plate 62 such that one wide wall of annulus 63 is formed in common with a portion of end plate 62 whereby the narrow walls of annulus 63 are parallel to the longitudinally extending axis of guide 61. In addition, an extension of the longitudinal axis of guide 61 would constitute the central axis of annulus 63. Unlike the embodiments described above, the inside wall of this annulus is one of the narrow dimensioned walls. Opening into the outside narrow wall of annulus 63 is a straight rectangular guide 64 which forms thereby an H-plane T junction. It may be noted that in the previous embodiments described an E-plane T junction was provided. Circularly disposed in the wall portion com-

mon to annulus 63 and end plate 62 is a multiplicity of equally spaced round coupling apertures for coupling between guide 61 and annulus 63. One aperture 63 is located on the opposite side of annulus 63 from the T junction formed by guide 64 and directly across therefrom. Each of the apertures is spaced from a next succeeding aperture by one guide wavelength of the frequency band of interest supported in annulus 63.

Disposed within guide 61 is a resonant cavity terminated at one end by end plate 62 and at the other end by a metallic conductive ring-shaped iris 66 coaxial to and spaced from a round metallic plate 67 to form a ring-shaped gap which is filled by a ring-shaped dielectric spacer 68. Ring 66 and plate 67 extend in a plane parallel to end plate 62. Round plate 67 is supported in the guide by dielectric spacer 68. Spacer 68, being of low dielectric constant, readily permits communication between the cavity and the rest of guide 61.

The operation of the embodiment of Fig. 6 may now be properly comprehended. Dominant mode wave energy propagating down rectangular guide 64 to be introduced into circular guide 61 divides equally into two portions at the H-plane T junction and proceeds to propagate respectively in opposite directions around annulus 63. However, the polarity of the electric field components of the two portions is of the same sense, as represented by the arrows in annulus 63 near the junction. The two portions proceed to propagate in their respective directions around the annulus until they meet at the opposite side of annulus 63 from the T junction. At this point, as indicated, the electric field will be a maximum, unlike the case in the previous embodiments described wherein an E-plane T junction fed the annulus. Accordingly, a magnetic field null exists at this point which is also the precise location of the aperture 65 communicating between the annulus 63 and circular guide 61. Since all the apertures are spaced one wavelength apart, magnetic field nulls will simultaneously occur at all the apertures by virtue of the fact that standing waves are set up in the annulus because of the reflection of the two portions of the wave energy at aperture 65. With the points of maximum electric field strength coinciding with the apertures in annulus 63, it may be seen that electric field components, all of the same polarity, will be excited in guide 61 and extend in a longitudinal direction therealong. Reference to the field patterns represented in Figs. 2A through 2E will demonstrate that the only mode compatible with this type of excitation is that of the circular magnetic TM_{0n} mode. What value is taken on is, of course, determined by the radius of guide 61 and the radial location of the apertures from the center of plate 62.

The resonant cavity in guide 61 merely serves to insure an efficient band transmission characteristic such that all the energy in the desired frequency band is coupled between rectangular guide 64 and circular guide 61. Needless to say, energy propagating initially in the circular guide, in the form of TM_{0n} mode energy in the direction toward the resonant cavity will be coupled into the rectangular guide in the form of dominant mode wave energy in reverse manner from the operation described above for the reverse direction of propagation.

The embodiment of Fig. 7, shown in transverse cross-sectional view, is in all respects similar to that of Fig. 6 except for the fact that the mode excited in circular guide 61 is the circular electric TE_{01} mode. This difference in result is accomplished by an arrangement wherein the coupling apertures are spaced one-quarter wavelength away from their positions in the embodiment of Fig. 6, such that they are located in Fig. 7 at the electric field nulls (and thus the magnetic field maxima) of the standing wave in annulus 63. This type of coupling arrangement will result in the magnetic field components within annulus 63 parallel to the wide walls and perpendicular to the narrow walls thereof simultaneously exciting radially

extending transverse magnetic field components in guide 61 which are everywhere of the same polarity in a radial sense. Inspection of the field patterns of Figs. 2A to 2E will demonstrate that the circular electric TE_{01} mode is the only mode that can be excited by such a coupling configuration.

Another type of end plate coupling arrangement is possible for exciting the TM_{0n} mode in round guide and is represented in the embodiment of Fig. 8. This arrangement is structurally the same as that of Fig. 6 except for the fact that the annulus 83 is arranged such that the wide dimensioned walls extend parallel to the longitudinal axis of guide 61 and the rectangular guide 84 feeding it also has its wide dimension extending in that direction. As a consequence, an E-plane T junction is formed by rectangular guide 84 and annulus 83 rather than the H-plane T junction of Fig. 6. It may be seen that in this arrangement dominant mode energy propagating from guide 84 to annulus 83 will split into two equal out-of-phase portions traveling in opposite directions through the annulus to form an electric field null at the opposite end of the annulus from the T junction; thus, magnetic field maxima are located at all the coupling apertures. However, these magnetic field maxima are at the narrow wall of the annulus and therefore the magnetic field components extend in a direction which is concentric to the transverse cross section of circular guide 61. This means that the wall currents in the narrow dimensioned walls of annulus 83 are at right angles to these magnetic field components. Accordingly, the apertures act as dipoles exciting radial electric field components in circular guide 61, with all the field components being of the same polarity in a radial sense. This type of excitation, of course, is compatible solely with the circular magnetic TM_{0n} mode in circular wave guide.

In certain of the figures of the drawings the coupling apertures are shown to be of rectangular shape and in others they are circular. It should be noted that with respect to the operation of any of the embodiments in accordance with the invention, the shape of the apertures is a matter of choice. In the physical fabrication of these structures, however, certain aperture shapes are easier to construct for certain of the structures than others.

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 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 hollow conductive pipe of circular transverse cross section supportive of electromagnetic wave energy at a given frequency, a hollow conductive wave guide of rectangular cross section supportive of electromagnetic wave energy at said given frequency, means for establishing a standing wave field pattern in said rectangular wave guide wherein the maxima and minima locations in space of the magnetic field component intensities coincides with the minima and maxima locations, respectively, of the electric field component intensities, and means for coupling said circular pipe and said rectangular guide comprising a conductively bounded cavity resonantly tuned to said given frequency having a multiplicity of coupling apertures disposed through a metallic wall partition common to said cavity and said rectangular wave guide with each of said apertures positioned at a null in the field pattern of said standing wave and a conductively bounded reactive iris interposed between said cavity and said hollow pipe for coupling wave energy therebetween.

2. The combination as recited in claim 1 wherein said common wall partition comprises a metallic conductive

end closure of said circular pipe and each of said apertures is located at a null in the electric field pattern of said standing wave.

3. The combination as recited in claim 1 wherein said common wall partition comprises a metallic conductive end closure of said circular pipe and each of said apertures is located at a null in the magnetic field pattern of said standing wave.

4. In an electromagnetic transmission system supportive of a band of frequencies extending between a lower frequency f_1 and an upper frequency f_3 and including a frequency f_2 therebetween, a band separation filter comprising first and second sections of conductively bounded circular wave guide supportive of wave energy within said band extending colinearly in longitudinal succession with adjacent ends of said sections spaced apart to form a gap in the boundary formed by said sections, a first annular chamber of rectangular cross section longitudinally disposed coextensive with at least a portion of each of said circular sections to provide a conductive boundary surrounding said gap, said first chamber proportioned to be resonant at said frequency f_2 , a second annular chamber of rectangular cross section having a wall thereof contiguous to a wall of said first chamber forming a common wall therebetween, a multiplicity of coupling apertures penetrating said common wall portion and disposed circumferentially about said first and second chambers, a section of rectangular wave guide supportive of traveling electromagnetic wave energy within said band coupled at one end thereof to said second chamber to form a T junction, and a band rejection filter coupled to said second section of circular wave guide at a distance from said gap equal to an odd integral number of quarter wavelengths of said frequency f_2 measured in a direction parallel to the longitudinal axis of said section, said band rejection filter being proportioned to anti-resonance at said frequency f_2 .

5. The combination according to claim 4 wherein the electromagnetic field pattern within said first chamber at frequency f_2 comprises regions of maximum electric field intensity coincident in space with regions of minimum magnetic field intensity and wherein said apertures are positioned along said common wall coextensive with said regions.

6. The combination according to claim 4 wherein the electromagnetic field pattern within said first chamber at frequency f_2 comprises regions of minimum electric field intensity coincident in space with regions of maximum magnetic field intensity and wherein said apertures are positioned along said common wall coextensive with said regions.

7. The combination according to claim 4 including means for energizing said first section of circular wave guide over a band of frequencies extending between frequencies f_1 and f_3 and including frequency f_2 therebetween, means for utilizing said applied wave energy between the frequencies f_1 to f_3 to the exclusion of said frequency f_2 connected to said second section of rectangular wave guide.

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