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2,719,271

WAVE GUIDE MODE TRANSFORMER

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FIG. 1

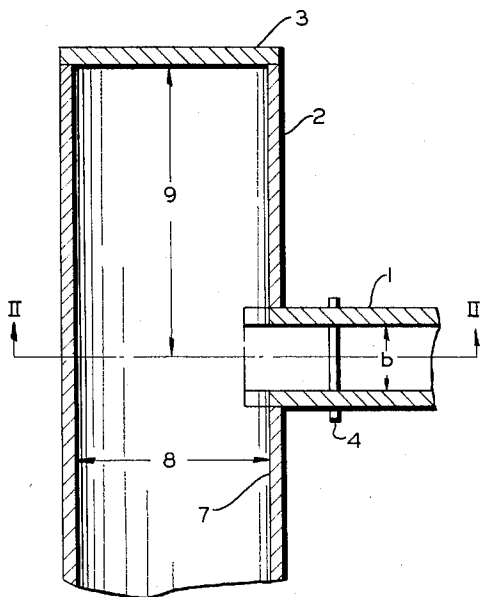


FIG. 3

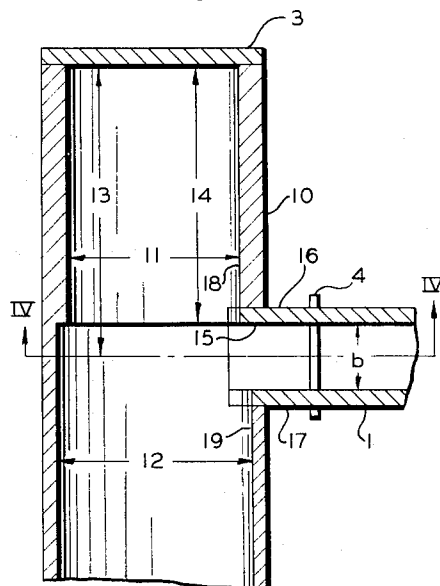


FIG. 2

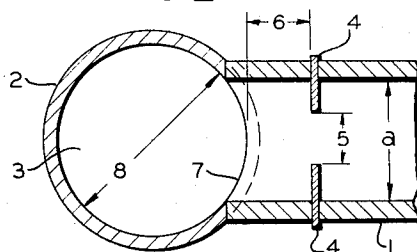
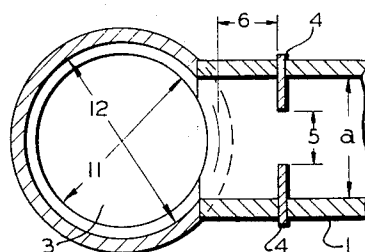


FIG. 4



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WAVE GUIDE MODE TRANSFORMER

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9 Claims. (Cl. 333—21)

This invention relates to the guided transmission of electric waves, and more particularly to apparatus for transforming the oscillation of electric waves from one mode to another as said waves are interchanged between cylindrical wave guides and other forms of transmission lines.

The subject matter of my present invention is disclosed in part in the application of Shepard Roberts, S. N. 510,990, filed November 19, 1943, for Rotatable Joints for Radio Wave Guide Systems. The rotatable joints therein described illustrate a valuable use for the mode transformers of my present invention.

It is frequently desirable in the guided transmission of electric waves to employ a cylindrical wave guide carrying waves in a mode of oscillation having symmetry about the longitudinal axis of the guide, such as the TM_{01} mode. In radio echo detection systems, for example, it is usual to guide electric waves to a rotatable antenna structure from a generator of the waves, and from such a structure to a receiver for the said waves. The use of the TM_{01} mode of oscillation in a cylindrical wave guide permits the advantageous use of a guide made of two coaxially aligned abutting sections, mutually relatively rotatable on their common axis, at the rotatable antenna structure. Rotation of one section of the wave guide relative to the other section does not disturb the TM_{01} waves therein and consequently a limitation upon the rotatability of the said structure is removed.

For various other reasons however, it is not desirable to use the TM_{01} mode of oscillation to transmit electric waves from one point to another. Among these reasons is the fact that the TM_{01} mode of oscillation is not the lowest mode for cylindrical wave guides. Such a guide having a diameter sufficiently great to carry energy in the TM_{01} mode is also large enough to carry energy in the TE_{11} mode, which does not have axial symmetry. The presence of more than one mode of oscillation in a wave guide results in a waste of power, since the power in the added mode is not used. It has been found to be more desirable to use a rectangular wave guide carrying energy in the lowest mode of oscillation, or a coaxial line as the main transmission line, and to provide a rotatable joint in the line where necessary.

Perhaps the simplest form of rotatable joint is that which makes use of two relatively short sections of cylindrical wave guide, excited and coaxially abutted as hereinafter set forth. The main transmission line is connected into each end of this joint, and energy is transferred through the joint in either direction from and to the said main transmission line. Waves being carried in a desired mode in the main transmission line must then be transformed into the TM_{01} mode upon entering a cylindrical wave guide section, and back to the transmission line mode upon leaving the cylindrical guide. Thus each end of a rotatable joint that is used in such an installation must be a mode transformer for the electric waves being carried.

In the past it has been usual to employ suitable an-

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tennas and supports within transmission lines at points of junction with rotatable joints to effect mode transformations. Such structural arrangements are difficult to construct, especially at the higher frequencies where wave lengths are short and machining tolerances consequently very close. These structures also cause numerous electrical difficulties. In the case where a rectangular wave guide is the main transmission line, the insertion of antenna structures is particularly objectionable, for it requires additional structure within the wave guides that makes the junction relatively very complicated.

In my invention I provide mode transformers having a rectangular wave guide coupled directly into the side of a cylindrical wave guide, without the use of coupling antennas or supports within either wave guide. The junction between the two wave guides is solid and has no moving parts. One end of the cylindrical wave guide is provided with an electrical closure, and this end forms a short circuited stub arranged in the different embodiments of my invention in novel ways to inhibit the formation of the unwanted TE_{11} mode of oscillation in the cylindrical wave guide and to facilitate the generation of the desired TM_{01} mode.

It is an object of my invention to provide a mode transformer for wave guide systems that will transform waves of energy in the lowest mode of oscillation in a rectangular wave guide into waves in the TM_{01} mode of oscillation in a cylindrical wave guide without the use of coupling antennas or the like.

It is a further object of my invention to provide such a transformer that will substantially inhibit the formation of waves in the TE_{11} mode in the cylindrical wave guide while simultaneously facilitating the generation of waves in the TM_{01} mode of oscillation therein.

It is a still further object of my invention to provide such a transformer that will be operable in either direction to transform waves in the desired mode in one wave guide into waves in the desired mode in another wave guide thereunto connected.

It is another object of my invention to provide such a mode transformer that will be simple and easy to construct, will have no moving parts, and will require no unusually close machining tolerances.

Other objects and features of my present invention will become apparent upon a careful consideration of the following detailed description when taken together with the accompanying drawings, the figures of which illustrate typical embodiments of the invention.

Fig. 1 illustrates in cross section a mode transformer constructed in accordance with my invention;

Fig. 2 is a cross section taken along line II—II of Fig. 1;

Fig. 3 is a cross section of another mode transformer constructed in accordance with the teachings of my invention; and

Fig. 4 is a cross section taken along line IV—IV of Fig. 3.

In Figs. 1 and 2 a rectangular wave guide 1, having width a and thickness b , is joined at one end thereof to a cylindrical wave guide 2 near one end thereof. The longitudinal axes of the two wave guides 1 and 2 are preferably mutually perpendicular, although variations in the angle between said axes is permissible. The said near end of the cylindrical wave guide 2 is closed by a metallic end closure 3. The junctions of the two wave guides 1 and 2 and of the cylindrical wave guide 2 with its end closure 3 are preferably made with solder, although any other means of providing mechanical fixity and electrical contact at said junctions is suitable. Diaphragms 4, made of relatively thin metallic plates, preferably rectangular in shape, are inserted one in each narrow wall of the rectangular wave guide 1, in a plane preferably substantially

perpendicular to the longitudinal axis of that wave guide 1. One diaphragm 4 may be used alone, if desired, but the use of two is preferred. When two diaphragms 4 are used, they are preferably co-planar.

The diaphragms 4 are provided for the purpose of effecting an impedance match between the two wave guides 1 and 2. The distance 5 between the two diaphragms 4 of Fig. 2 and the distance 6 from the plane of the diaphragms 4 to the inner wall 7 of the cylindrical wave guide 2 are both chosen to provide the desired impedance match. These dimensions 5 and 6 are commonly arrived at by experiment and are susceptible of various satisfactory combinations. One satisfactory set of dimensions is disclosed hereinbelow for similar matching diaphragms used in the apparatus of Figs. 3 and 4.

The diameter 8 of the cylindrical wave guide 2 should be large enough to permit the passage of energy in the TM₀₁ mode of oscillation, but not large enough to permit the passage of higher modes. The cut-off diameter for the TM₀₁ mode of oscillation is given by the expression

$$d=0.76\lambda$$

where d is the diameter 8 of the cylindrical wave guide 2, and λ is the free-space wave length of energy at the frequency being transmitted. Since the cut-off diameter for the TE₁₁ mode of oscillation is equal to 0.58λ , a cylindrical wave guide 2 of large enough diameter to carry the TM₀₁ mode of oscillation will also sustain oscillations in the TE₁₁ mode. The next highest mode of oscillations for cylindrical wave guides is the TE₂₁ mode, for which the cut-off diameter is equal to 0.97λ . Therefore, in order not to permit the passage of the TE₂₁ mode of oscillation, the diameter 8 of the cylindrical wave guide 2 should be smaller than 0.97λ . Hence the diameter 8 will preferably be determined at a value between 0.76λ and 0.97λ . In practice, a diameter 8 of a magnitude approaching 0.97λ is preferably used, as smaller diameters 8 cause relatively greater attenuation of the signal being carried by the wave guide 2 than do larger diameters.

The junction point of the two wave guides 1 and 2 may be considered to be that point at which the two longitudinal axes of said wave guides cross, although it is to be understood that energy is interchanged between the two wave guides 1 and 2 in a region about such a point. The distance 9 from such a point to the end closure 3 may be regarded as the closed stub length, and should be chosen and adjusted at a value which will inhibit the propagation of waves in the TE₁₁ mode. The stub length 9 is accordingly preferably substantially equal to an odd number of quarter-wave lengths in the cylindrical wave guide 2 of energy in the TE₁₁ mode of oscillation.

The rectangular wave guide 1 is of an ordinary kind in which the width a and thickness b are of magnitudes that will permit the said wave guide 1 to carry energy in the lowest or TE₁₀ mode only. In the TE₁₀ mode for rectangular wave guides, the electric vector is in a direction transverse to the longitudinal axis of the wave guide and perpendicular to the wide walls thereof. Thus, in Figs. 1 and 2, the aforesaid electric vector will be substantially parallel to the line indicating the narrow, or b dimension, and perpendicular to the line indicating the wide, or a dimension.

The apparatus of Figs. 1 and 2 operates in a relatively simple manner. For the sake of explanation it will be assumed that energy is being transferred from the rectangular wave guide 1 to the cylindrical wave guide 2, although it should be borne in mind that energy may be passed in either direction in this apparatus. Accordingly, energy in the TE₁₀ mode for rectangular wave guides enters the cylindrical wave guide 2 from the rectangular wave guide 1. In the region of entry, this aforementioned TE₁₀ energy may generate waves of many modes for cylindrical wave guides. However, since the diameter 8 has a magnitude that is less than 0.97λ , as hereinabove explained, those modes higher than the TM₀₁ and

the TE₁₁ modes will quickly be attenuated to insignificant intensities, and may be regarded as absent for all practical purposes.

The newly generated waves in the TM₀₁ and TE₁₁ modes will proceed along the cylindrical wave guide 2 away from the aforesaid region. Those waves that enter the closed stub and encounter the end closure 3 will be reflected back toward the aforesaid region, where they will encounter other newly generated waves. Since the length 9 of the stub is substantially equal to an odd number of quarter wave lengths in the wave guide 2 for the TE₁₁ mode, reflected TE₁₁ mode waves will arrive at the aforesaid region substantially 180 degrees out of phase with newly generated waves present in said region, and the said TE₁₁ mode waves will substantially mutually cancel each other. As a consequence, there will be a relatively great attenuation of waves in the TE₁₁ mode. From another aspect, it may be said that the mode transformer of Figs. 1 and 2 presents a relatively high input impedance to the TE₁₁ mode.

As is known to those skilled in the art, the wave length in the wave guide will be different for waves in different modes of oscillation at the same frequency. In the illustrative mode transformer of Figs. 1 and 2, air filled wave guides are used. Thus, in the cylindrical wave guide 2, a wave in the TM₀₁ mode is longer than a wave in the TE₁₁ mode at the same frequency. Therefore, a depth 9 for the closed stub end of the cylindrical wave guide 2 that will result in substantial cancellation of the TE₁₁ mode waves will not cause the cancellation of waves in the TM₀₁ mode.

In order that the most favorable impedance match may be had between the two wave guides 1 and 2 for the generation of waves in the TM₀₁ mode, the diaphragms 4 are installed in the rectangular wave guide 1. These diaphragms 4 introduce an inductive shunt susceptance into the mode transformer system. As the spacing 5 between the diaphragms 4 is decreased, this susceptance is increased. This spacing 5 is preferably chosen for the most favorable impedance match for the generation and propagation of waves in the TM₀₁ mode.

When conversely it is sought to transform waves in the TM₀₁ mode in the cylindrical wave guide 2 into waves in the TE₁₀ mode in the rectangular wave guide 1, the above described action will occur in reverse. Due to the aforementioned favorable impedance conditions, waves in the TM₀₁ mode will be present in relatively great strength at the region of junction of the transverse guides 1 and 2. These waves in the TM₀₁ mode in the cylindrical wave guide 2 may generate waves in many modes in the rectangular wave guide 1. However, the dimensions a and b are such that as hereinabove stated, only waves in the TE₁₀ mode for rectangular wave guides will be propagated in the wave guide 1. All other modes will be substantially attenuated to insignificant values of intensity. Thus, it is seen that the apparatus of Figs. 1 and 2 may be used to transform electric waves from one mode in a rectangular wave guide 1 into another mode in a cylindrical wave guide 2, or vice versa.

It is possible to choose a value of the diameter 8 for the cylindrical wave guide 2 that will permit the stub end of said wave guide to effect substantially complete cancellation of the TE₁₁ mode waves and simultaneously bring about substantially complete reenforcement to the TM₀₁ mode waves. As hereinabove mentioned, the wave length in the wave guide 2 of waves at a given frequency is different for different modes. In general, for an air-filled wave guide, the wave length in the guide of energy being carried therein is given by the relation;

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{\lambda_c}\right)^2}}$$

where:

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λ_g = the length in the wave guide of a wave of the energy being carried;
 λ = the free-space wave length of that energy; and
 λ_c = the free-space cut-off wave length for the particular mode in which the energy is being carried.

Since the cut-off wave length in a wave guide differs for different modes of propagation, the wave length in the guide will also differ for different modes of propagation. In a cylindrical wave guide, the cut-off wave length for the TM_{01} mode is given by the relation:

$$\lambda_c^{TM_{01}} = 1.31d$$

where

$\lambda_c^{TM_{01}}$ = the free-space cut-off wave length for the TM_{01} mode and d is the diameter of the cylindrical wave guide.

Similarly:

$$\lambda_c^{TE_{11}} = 1.71d$$

where

$\lambda_c^{TE_{11}}$ = the free space cut-off wave length for the TE_{11} mode.

Whence, by simple substitution, the following relations may be had:

$$\lambda_g^{TM_{01}} = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{1.31d}\right)^2}} \quad (1)$$

and

$$\lambda_g^{TE_{11}} = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{1.71d}\right)^2}} \quad (2)$$

where:

$\lambda_g^{TM_{01}}$ = the wave length in the cylindrical wave guide of energy at the operative frequency in the TM_{01} mode, and

$\lambda_g^{TE_{11}}$ = the wave length in the cylindrical wave guide of similar energy in the TE_{11} mode.

If now the diameter d be given such a value that

$$\lambda_g^{TE_{11}} = \frac{2}{3} \lambda_g^{TM_{01}}$$

then it becomes apparent by simple algebraic process that

$$\frac{3}{4} \lambda_g^{TE_{11}} = \frac{1}{2} \lambda_g^{TM_{01}}$$

From this last relation it is evident that a section of cylindrical wave guide having this special value of diameter d may at one and the same time be three-quarters of a wave length long for the TE_{11} mode and one-half a wave length long for the TM_{01} mode, both wave lengths being in-the-guide wave lengths. Thus, in the apparatus of Figs. 1 and 2, if the diameter 8 be given the special magnitude that will result in the relation

$$\lambda_g^{TE_{11}} = \frac{2}{3} \lambda_g^{TM_{01}}$$

and, if the stub length 9 be made to be substantially equal to three-quarters of the length in the wave guide 2 of a wave in the TE_{11} mode, the stub end of the wave guide 2 will simultaneously substantially wholly cancel the TE_{11} mode and substantially wholly reenforce the TM_{01} mode of oscillation.

The diameter 8 of the cylindrical wave guide 2 that will render

$$\lambda_g^{TE_{11}} = \frac{2}{3} \lambda_g^{TM_{01}}$$

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may be found by simple algebra from the relation:

$$\frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{1.71d}\right)^2}} = \frac{2}{3} \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{1.31d}\right)^2}}$$

which is simply a substitution of equivalents obtained from relations (1) and (2) as hereinabove set forth; whence it may be shown that

$$d = 0.884\lambda$$

Thus the diameter 8 of the cylindrical wave guide 2 should be equal to 0.884 times the free space wave length of the energy being carried therein to render

$$\lambda_g^{TE_{11}} = \frac{2}{3} \lambda_g^{TM_{01}}$$

Thus, in the apparatus of Figs. 1 and 2, when the diameter 8 of the cylindrical wave guide 2 is chosen to be 0.884λ , and the stub length 9 is equal to three-quarters of a TE_{11} mode wave length in the wave guide, the said stub length 9 will simultaneously be equal to one-half of a TM_{01} mode wave length in the wave guide 2. By the ordinary principles of wave propagation, the stub end of the wave guide 2 will then simultaneously effect substantially complete cancellation of the TE_{11} mode waves, and substantially complete reenforcement of the TM_{01} mode waves. Inasmuch as the stub length 9 has substantially an ideal length for the TM_{01} mode, the amount of susceptance required to be provided by the diaphragms 4 will be only very slight.

The diameter 0.884λ is not the largest that may be used for the purposes of the hereindisclosed mode transformers. As hereinabove set forth, diameters 8 approaching the value 0.97λ are desirable. A diameter 8 of the value 0.884λ may result in undesirable attenuation of the transmitted signal. Accordingly, another value for the diameter 8 has been investigated, and found useful. When the diameter 8 is of a value equal to 0.94λ , the following relation is true:

$$\lambda_g^{TM_{01}} = 1.34 \lambda_g^{TE_{11}}$$

Then it can be shown that when the closed stub length 9 has a value equal to three-quarters of a TE_{11} mode wave length in the wave guide 2, the said stub length 9 simultaneously has a value equal to 0.56 of a TM_{01} wave length in the said wave guide. The value

$$0.56 \lambda_g^{TM_{01}}$$

is substantially close to the value one half

$$\lambda_g^{TM_{01}}$$

so that there is still a relatively good impedance match for the TM_{01} mode of oscillation. Some additional shunt susceptance may be provided by the diaphragms 4 if desired to effect the best possible impedance match.

In Figs. 3 and 4 there is illustrated a modification of my invention that combines the desirable features of smaller and larger diameters of the cylindrical wave guide portion of the mode transformer. The rectangular wave guide 1 is at one end inserted into the side of a cylindrical wave guide 10 near an end thereof. The said end is closed by an end closure 3 substantially identical to the end closure 3 of Fig. 1. The internal diameter 11 of the closed stub portion of the cylindrical wave guide 10 is smaller than the internal diameter 12 of the remainder of the said cylindrical wave guide. The portion of smaller diameter 11 does not extend the full distance 13 to the center line of the rectangular wave guide 1, but extends a lesser distance 14 to the inner surface 15 of the upper wide wall 16 of the rectangular wave guide 1. The wave guide 1 is flush at the ends of its upper and lower walls 16 and 17 with the adjacent inner surfaces 18 and 19 respectively of the cylindrical wave guide 10. Other parts bearing the same reference characters as corresponding parts

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in the apparatus of Figs. 1 and 2 are substantially identical to said corresponding parts.

With the apparatus of Figs. 3 and 4, it is possible to choose a value for the diameter 11 of the cylindrical stub in the neighborhood of 0.884λ , and at the same time have the diameter 12 of the remainder of the cylindrical wave fixed at an advantageous value, such as 0.94λ . A preferred value for the length 14 of the cylindrical stub may be determined experimentally. I have determined many sets of preferred values for the diameters 11 and 12 and the stub length 14. One such preferred set of values is herein presented.

The stub diameter 11 = 0.845λ

The stub length 14 = 0.835λ

The larger diameter may remain 0.94λ

I have further determined a set of satisfactory values for the opening 5 in the inductive diaphragms 4 and their spacing 6 from the lower inner wall 19 of the cylindrical wave guide 10. These values are here presented:

The opening 5 = 0.525λ

The spacing 6 = 0.144λ

The hereinabove stated values of various dimensions are not to be regarded as the only workable values, but merely as an example of one set of preferred values that yield successful performance.

A rectangular wave guide 1 having the dimensions:

$$a = 0.72\lambda$$

and

$$b = 0.32\lambda$$

functions well in either of the mode transformers illustrated in the drawings.

Although I have shown and described only certain specific embodiments of my invention, I am fully aware of the many modifications possible thereof. Therefore this invention is not to be limited except insofar as is necessitated by the prior art and the spirit of the appended claims.

I claim:

1. A wave transformer for electric waves comprising a transmission line adapted to carry electric waves, a hollow cylindrical wave guide adapted to carry electric waves in the TM_{01} and TE_{11} modes of oscillation, the diameter of said wave guide being such that a wave in said TM_{01} mode is substantially three halves the length of a wave in said TE_{11} mode, and an end closure in one end of said wave guide, said transmission line being at one end joined and electrically coupled to said wave guide through a hole in the side thereof near said end closure, the distance measured along the longitudinal axis of said wave guide from said end closure to the mid point of said hole projected perpendicularly to said axis being simultaneously substantially equal to three quarters of a wave length in said TE_{11} mode and one half a wave length in said TM_{01} mode.

2. A wave transformer for electric waves comprising a transmission line adapted to carry electric waves, a hollow cylindrical wave guide adapted to carry electric waves in the TM_{01} and TE_{11} modes of oscillation, and an end closure in one end of said wave guide, said transmission line being at one end joined and electrically coupled to said wave guide through a hole in the side thereof near said end closure, the diameter of that portion of said wave guide between said transmission line and said end closure being smaller than the diameter of the remainder of said wave guide, said smaller diameter and the length of said portion being relatively so proportional that waves in the TE_{11} mode proceeding through said wave guide from the region of said hole in a direction away from said end closure are substantially wholly cancelled by like waves reflected from said end closure, while simultaneously waves in the TM_{01} mode proceeding through said wave guide from the region of said hole in a direc-

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tion away from said end closure are substantially wholly reinforced by like waves reflected from said end closure.

3. A wave transformer for microwaves comprising a hollow rectangular wave guide adapted to carry microwaves, a cylindrical wave guide closed at one end and adapted to carry microwaves in a first mode having a symmetry about the longitudinal axis thereof and in a second mode not having such symmetry, said rectangular wave guide and said cylindrical wave guide being electrically coupled together by an aperture in the side of said cylindrical wave guide, the location of said aperture defining a stub length of cylindrical wave guide related to the wavelength of said second mode in said guide to suppress said second mode and to reinforce said first mode by reflection from said closed end of said cylindrical wave guide.

4. A wave transformer for microwaves comprising a rectangular wave guide adapted to carry microwaves, a hollow cylindrical wave guide adapted to carry microwaves in a first mode having symmetry about the longitudinal axis thereof and in a second mode not having such symmetry, the diameter of said cylindrical wave guide being such that a wave in said first mode has a wavelength substantially three halves of the wavelength of a wave in said second mode, an end closure in one end of said cylindrical wave guide, said rectangular wave guide being at one end joined and electrically coupled to said cylindrical wave guide through a hole in the side thereof near said end closure, the distance measured along the longitudinal axis of said cylindrical wave guide from said end closure to the mid point of said hole projected perpendicularly to said axis being substantially equal to three quarters of a wavelength of a wave in said second mode in said cylindrical wave guide.

5. A wave transformer for microwaves comprising a rectangular wave guide adapted to carry microwaves, a hollow cylindrical wave guide adapted to carry microwaves in a first mode of oscillation having symmetry about the longitudinal axis thereof and in a second mode of oscillation not having such symmetry, an end closure in one end of said cylindrical wave guide, said rectangular wave guide being at one end joined and electrically coupled to said cylindrical wave guide through a hole in the side thereof near said end closure, the diameter of that portion of said cylindrical wave guide between said rectangular wave guide and said end closure being smaller than the diameter of the remainder of said cylindrical wave guide, said smaller diameter being such that a wave in said first mode has a wavelength substantially three halves of the wavelength of a wave in said second mode, and the length of said portion being relatively so proportioned that waves in said second mode proceeding through said wave guide from the region of said hole in a direction away from said end closure are substantially wholly cancelled by like waves reflected from said end closure, while simultaneously waves in said first mode proceeding through said cylindrical wave guide from the region of said hole in a direction away from said hole are substantially reinforced by like waves reflected from said end closure.

6. A wave transformer for electrical waves comprising, a hollow rectangular wave guide adapted to carry electric waves, a hollow cylindrical wave guide closed at one end and adapted to carry waves in a first mode having symmetry about the longitudinal axis thereof and a second mode not having such symmetry, said rectangular wave guide and said cylindrical wave guide being electrically coupled together by an aperture in the side of said cylindrical wave guide near said closed end thereof, said aperture being so located with respect to the closed end of said cylindrical wave guide that electric waves in said second mode reflected from said closed end cancel similar waves in said second mode existing in said cylindrical wave guide in the vicinity of said aperture and that waves in said first mode reflected from said closed

end effectively reinforce similar waves in said first mode existing in the cylindrical wave guide in the vicinity of said aperture.

7. Apparatus for transforming electromagnetic energy from a TE_{11} mode to a TM_{01} mode or vice versa comprising, in combination, a hollow section of rectangular wave guide, a hollow section of cylindrical wave guide, an end closure in one end of said cylindrical wave guide, said rectangular wave guide being at one end joined and electrically coupled to said cylindrical wave guide through a hole in the side thereof near said end closure, the diameter of said cylindrical wave guide being between .884 and .970 of the free space wave length of the electromagnetic energy being propagated within the apparatus and the distance measured along the longitudinal axis of said cylindrical wave guide from said end closure to the midpoint of said hole projected perpendicularly to said axis being substantially equal to .75 of the wave length in the cylindrical wave guide of the electromagnetic energy in the TE_{11} mode guide.

8. Apparatus for transforming electromagnetic energy from a TE_{11} mode to a TM_{01} mode or vice versa comprising, in combination, a hollow section of rectangular wave guide, a hollow section of cylindrical wave guide, an end closure in one end of said cylindrical wave guide, said rectangular wave guide being at one end joined and electrically coupled to said cylindrical wave guide through

an aperture in the side thereof near said end closure, the diameter of that portion of said cylindrical wave guide between said rectangular wave guide and said end closure being approximately .845 of the free space wave length of the electromagnetic energy being propagated within the apparatus, the diameter of the remainder of said cylindrical wave guide being approximately .940 of said wave length and the distance measured along the longitudinal axis of said cylindrical wave guide from said end closure to the midpoint of said aperture projected perpendicularly to said axis being approximately .835 of said wave length.

9. In a mode transformer of the type claimed in claim 8, wherein an inductive iris is positioned within said rectangular wave guide and spaced from the juncture of said rectangular wave guide and said cylindrical wave guide by a distance of approximately .144 of the free space wave length of the energy being propagated.

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