Aug. 19, 1958 E. T. HARKLESS 2,848,691

DIRECTIONAL COUPLER

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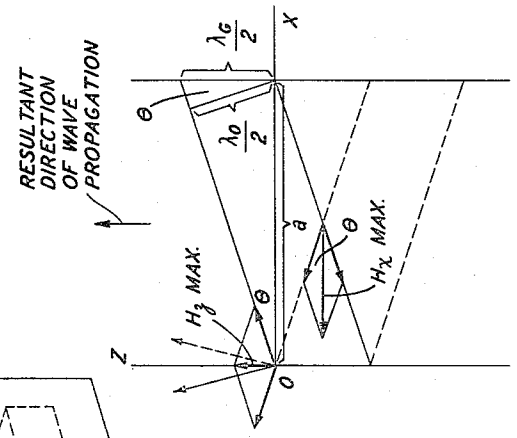

FIG. 2

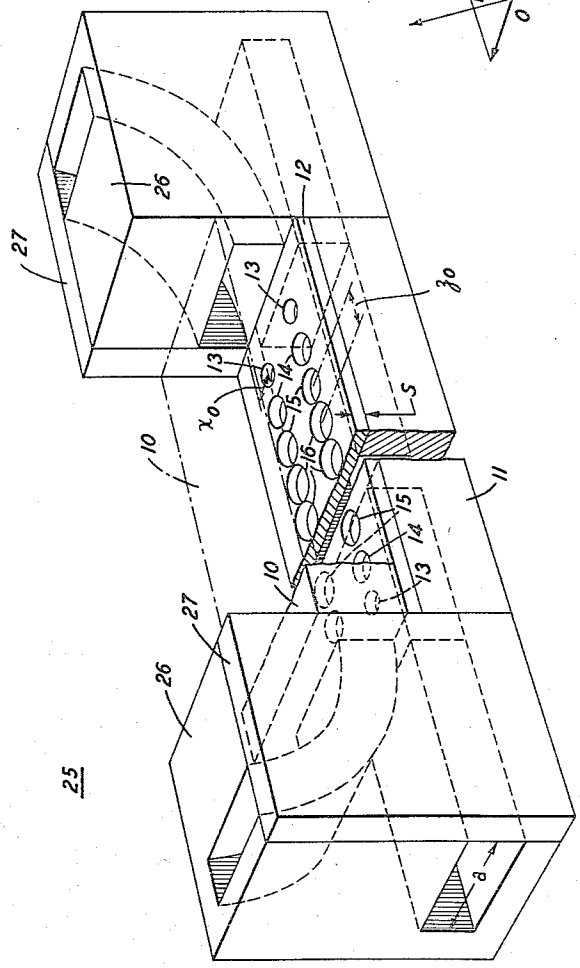

FIG. 1

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DIRECTIONAL COUPLER

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2 Claims. (Cl. 333—10)

This invention relates to directional couplers for wave guides and more particularly to arrangements for increasing the directivity of such couplers and for making the couplers more nearly uniformly effective over a relatively broad band of operating frequencies.

An object of the invention is to obtain relatively high directivity at one or more selected frequencies.

Another object is to make the coupling substantially constant over a wide frequency band.

A feature of the invention is a novel critical spacing of a coupling hole with respect to the longitudinal axis of a wave guide whereby maximum directivity is imparted to a single hole at a selected frequency.

Another feature is the selection of the thickness of a coupling plate between two wave guides to provide a substantially uniform coupling over a wide frequency band.

One or more of the various features of the invention may be used together or may be combined with a known type of critical spacing of a plurality of coupling holes along the length of the coupling plate to increase the directivity at a frequency or frequencies which may differ from the frequency at which a single hole develops its maximum directivity.

In accordance with the invention, two hollow-pipe wave guides are employed extending in a common direction over a portion of their respective lengths and having a common wall extending longitudinally in the said direction. One or more means for coupling the two wave guides in the region of the common wall are provided such as a coupling hole or aperture in the common wall, the cross-sectional dimensions of which preferably are small compared to a wavelength in one or both of the wave guides at the operating frequency. Such coupling means is located at a critical point in the common wall about which the field pattern in one or both of the wave guides would be unsymmetrical in the absence of the coupling means. Generally such a coupling point is off-center with respect to the central longitudinal axis of one or both of the wave guides. Such placement of the coupling means may be utilized to render the coupling due to a single coupling means inherently directional.

In accordance with the invention also the thickness of the common wall is made a material fraction of the width of the wider side wall in the case of rectangular wave guides, or, more generally, a material fraction of a wavelength in the wave guide at the operating frequency. The thickness is so proportioned that the efficiency of coupling between the respective wave guides with reference to transmission in the desired direction in the second or excited wave guide is rendered substantially uniform over an extended frequency band.

In the drawings,

Fig. 1 is a perspective view, partly broken away, showing a preferred embodiment of the invention; and

Fig. 2 is a diagrammatic plan view of a wave guide of rectangular cross-section showing wave properties useful in explaining the invention.

Referring to Fig. 1, a pair of wave guides 10, 11 of

rectangular cross-section are shown as having a common wall comprising a plate 12. The wave guides are coupled together for the passage of electromagnetic waves therebetween by means of a plurality of holes 13–16 extending through the plate 12. Each hole is located at a critical distance x_0 from the nearest side wall and the holes are spaced apart at a critical interval z_0. Furthermore, the thickness s of the coupling plate is suitably chosen. A total of twelve holes, six on each side of the center line, are shown by way of example, but a greater or a lesser number of holes may be provided as desired. As will be more fully explained hereinafter, the several advantages of the invention may be obtained either separately or in combination by proper selection of hole locations and coupling plate thickness.

To begin with, the distance x_0 of a hole from the nearest side wall may be adjusted relatively to the length a of the long side of the rectangular cross-section of the wave guide to secure for a single hole the property of directional coupling. That is, an electromagnetic wave passing through one of the wave guides will excite by action through a single hole in the coupling plate a unidirectional wave in the other wave guide. By a unidirectional wave is meant one which exists substantially from the position of the hole in one direction only along the wave guide, which direction is the direction of propagation of the wave. The location of the hole for the purpose of securing directional coupling is frequency-sensitive, providing maximum directivity for a selected single frequency. By directivity is meant the ratio of the amplitude of the wave propagated in the preferred direction to the amplitude of the wave propagated in the reverse direction, which latter will of course always exist in any practical embodiment although it may be made exceedingly weak. The directivity will fall off more or less sharply at frequencies either above or below the frequency for which the hole position is selected.

Secondly, to increase the amount of coupling, thereby strengthening the wave propagated in the desired direction, a plurality of coupling holes may be provided. The added holes may be spaced different distances from the side wall in order to impart a high degree of directivity at a variety of frequencies spread over a band, or, it may be preferred that all the holes be spaced from the side wall by a uniform distance x_0 as in the embodiment illustrated in the drawings. The holes may be placed on both sides of the center line of the coupling plate, if desired. The longitudinal spacing z_0 of the holes may be made a quarter wavelength at any selected frequency or at selected frequencies spaced over a band. The longitudinal rows of holes will then provide additional directivity because the holes in each row introduce phase oppositions as in the directional coupler disclosed and claimed in United States Patent 2,562,281, issued July 31, 1951, to W. W. Mumford. The frequency of maximum directivity for the rows of holes due to the effect described in the Mumford patent may be selected to be different from the frequency of maximum directivity for the individual holes, thereby promoting relatively high directivity extending between the two selected frequencies.

Thirdly, the thickness s of the coupling plate may be chosen to provide a more uniform degree of coupling over the selected frequency band. There may be obtained by this means a maximum amplitude of the forward wave for a predetermined frequency which may be located between the two frequencies of maximum directivity hereinbefore mentioned.

In the embodiment shown in Fig. 1, the wave guide structures are combined in a unitary structure which may be formed of suitable metal, such as aluminum. The wave guides 10, 11 are shown as composed of two similar channel members fastened on opposite sides of the cou-

pling plate 12 thereby defining two parallel extending wave paths separated by a perforated common wall. Transition members 25 are provided for bringing the respective wave guides into convenient positions for coupling into a wave guide system. Each transition member is shown as comprising a recessed block 26 and a cover plate 27. The respective parts of the complete structure may be fastened together in any suitable manner, for example by means of metal dowels, machine screws, solder, etc., in accordance with known practice. The upper wave guide is shown as being turned through a 90 degree angle in each transition member, giving access to the upper wave guide vertically from above.

Fig. 2 shows a diagrammatical plan view of a rectangular wave guide of width a. Coordinate axes are chosen about an origin in the left-hand side wall of the guide so that the x-axis is transverse to the longitudinal axis of the wave guide, the z-axis is parallel to the longitudinal axis of the wave guide, and the y-axis is perpendicular to the wider wall of the wave guide, extending downward into the paper. As is well known, a TE_{10}-mode wave may be synthesized from two TEM waves each propagating in a direction at an acute angle θ with respect to the longitudinal axis of the wave guide and reflected back and forth between the narrower walls of the wave guide. At any particular position in the wave guide one component TEM wave is propagating at a plus θ angle while the other component TEM wave is propagating at a minus θ angle.

Using the nomenclature of M. Surdin in his article entitled "Directive Couplers in Wave Guides," published in the Journal of the Institution of Electrical Engineers, volume 93, part III A, pages 725–736, at page 726:

$$\left.\begin{aligned} E_y &= \frac{k}{\gamma_1}\sin\frac{\pi x}{a}\epsilon^{-j\gamma_1 z} \\ H_x &= -\sin\frac{\pi x}{a}\epsilon^{-j\gamma_1 z} \\ H_z &= \frac{j\alpha_1}{\gamma_1}\cos\frac{\pi x}{a}\epsilon^{-j\gamma_1 z} \end{aligned}\right\} \quad (1)$$

represents the several components of a wave of TE_{10}-mode in a rectangular wave guide propagating in the positive z-direction of Fig. 2 of this application. A time factor such as $e^{j\omega t}$ is omitted from each component for brevity but is understood to be included. In Equations 1, α_1 is an abbreviation for π/a where a is the width of the wider wall of the wave guide. In the equations, also, k equals $2\pi/\lambda_0$, where λ_0 is the wavelength in free space at the operating frequency of the wave guide. Similarly, γ_1 equals $2\pi/\lambda_G$, where λ_G is the wavelength in the wave guide at the operating frequency. The quantities k and γ_1 are the phase constants in free space and in the wave guide respectively, and are sometimes referred to as "wave numbers" in the sense that each represents the number of times a phase shift of one radian occurs in a unit distance in the direction of propagation. A wave number in this sense is 2π times as great as another quantity sometimes defined as a wave number in the sense of the number of complete cycles per unit distance. To avoid confusion the term "phase constant" will be used hereinafter in preference to the term "wave number."

For a TE_{10}-mode wave propagating in the negative z-direction, Surdin gives

$$\left.\begin{aligned} E_y &= \frac{k}{\gamma_1}\sin\frac{\pi x}{a}\epsilon^{j\gamma_1 z} \\ H_x &= \sin\frac{\pi x}{a}\epsilon^{j\gamma_1 z} \\ H_z &= \frac{j\alpha_1}{\gamma_1}\cos\frac{\pi x}{a}\epsilon^{j\gamma_1 z} \end{aligned}\right\} \quad (2)$$

In Equations 1 and 2 the factor j in the fraction $j\alpha_1/\gamma_1$ indicates the time phase of the H_z component as compared to the E_y and H_x components. In particular the j indicates that if the E_y and H_x components have a time variation given by cos ωt, then the H_z component has a time variation given by sin ωt. The equations imply that all the wave components vary sinusoidally with time.

General expressions for the forward and backward wave respectively for the case of two rectangular wave guides coupled through a hole in a negligibly thin common wall are given by Surdin at page 727:

$$\left.\begin{aligned} A_1 &= \frac{j\gamma_1}{ab}(M_1H_{1x}H_{0x} + M_2H_{1z}H_{0z} - PE_{1n}E_{0n}) \\ B_1 &= \frac{j\gamma_1}{ab}(-M_1H_{1x}H_{0x} + M_2H_{1z}H_{0z} - PE_{1n}E_{0n}) \end{aligned}\right\} \quad (10)$$

In these equations transverse electric waves of TE_{10}-mode are assumed in both of the rectangular wave guides, and

A_1 is the relative amplitude of the wave that is propagated in the excited wave guide in the same direction as is the impressed wave in the exciting wave guide;

B_1 is the relative amplitude of the wave that is propagated in the excited wave guide in the reverse direction from that of the impressed wave in the exciting wave guide;

j indicates time phase quadrature of the waves in the excited wave guide with respect to the wave in the exciting wave guide;

γ_1 is the phase constant for a TE_{10} wave in either wave guide, where the two guides are alike;

a is the wider dimension of the cross-section of the wave guide, where the two guides are alike;

b is the narrower dimension of the cross-section;

H_{0x} and H_{0z} are the magnitudes as defined in Equations 1 for the transverse and longitudinal components, respectively, of the magnetic field of the TE_{10} wave in the exciting wave guide as those components would be at the proposed position of the coupling hole if no hole existed;

E_{0n} is the magnitude of the electric component of the field of the TE_{10} wave in the exciting wave guide under similar circumstances;

M_1 and M_2 are multipliers, termed polarizabilities by Surdin, which determine magnitudes of magnetic moments M_1H_{0z} and M_2H_{0z}, respectively, without specifying the directions of the magnetic moments, appertaining to equivalent magnetic dipoles conceived of as being set up at the position of the coupling hole;

P is a multiplier which determines the magnitude without specifying the direction of an electric moment PE_{0n} of an equivalent electric dipole conceived of as being set up at the position of the coupling hole;

H_{1x} and H_{1z} are the magnitudes as defined in Equations 1 of the transverse and longitudinal components, respectively, of the magnetic field of a TE_{10} wave in the excited wave guide as those components would be at the proposed position of the coupling hole if the wave guide were excited and if no hole existed; and

E_{1n} is the magnitude of the electric component of the field of the TE_{10} wave in the excited wave guide under similar circumstances.

It will be noted that the effectiveness of the equivalent magnetic dipole in exciting a TE_{10} wave in the excited wave guide is expressed as proportional to the mechanical couple exerted upon the magnetic dipole which is evaluated by multiplying the magnetic moment of the dipole by the appropriate magnetic component of the field of the TE_{10} wave excited. A similar expression holds for the effectiveness of the equivalent electric dipole. The respective expressions of effectiveness are $M_1H_{1x}H_{0x}$, $M_2H_{1z}H_{0z}$, and $PE_{1n}E_{0n}$. The values of the multipliers M_1, M_2, and P are dependent upon the size and shape of the coupling hole, the latter being assumed of small dimensions compared to the shortest operating wavelength involved. The plus and minus signs in the Equations 10 determine the manner in which the effects of the equivalent dipoles combine to produce the over-all effect of coupling between the wave guides through the coupling

hole. Destructive interference is to be expected to result from the combination of terms of opposite sign. In general the forward and backward waves in the excited wave guide are of unequal amplitude and in special cases either the forward wave or the backward wave may be absent due to cancellation of terms.

The relative values of the polarizabilities are given by Surdin for a circular hole as

$$M_1=M_2=2P \tag{8}$$

By substituting from Surdin's Equation 8 into his Equation 10 the latter equations may be simplified for present purposes as

$$\left.\begin{aligned} A_1&=\frac{j\gamma_1 P}{ab}(2H_{1x}H_{0x}+2H_{1z}H_{0z}-E_{1n}E_{0n}) \\ B_1&=\frac{j\gamma_1 P}{ab}(-2H_{1x}H_{0x}+2H_{1z}H_{0z}-E_{1n}E_{0n}) \end{aligned}\right\} \tag{11}$$

Equations 11 and following relate to applicant's analysis based upon Surdin's Equations 1, 2, 8, and 10, the numbering of Equations 11 and following, however, being independent of the numbering of equations in Surdin's article.

For the case wherein the two wave guides are of the same shape and size

$$\left.\begin{aligned} H_{1x}&=H_{0x}=|H_x| \\ H_{1z}&=H_{0z}=|H_z| \\ E_{1n}&=E_{0n}=|E_y| \end{aligned}\right\} \tag{12}$$

Substituting the values of the component magnitudes from Equations 12 and 1 into Equations 11,

$$A_1=\frac{j\gamma P}{ab}\left[2\sin^2\frac{\pi x}{a}+2\left(\frac{\alpha}{\gamma}\right)^2\cos^2\frac{\pi x}{a}-\left(\frac{k}{\gamma}\right)^2\sin^2\frac{\pi x}{a}\right] \tag{13}$$

$$B_1=\frac{j\gamma P}{ab}\left[-2\sin^2\frac{\pi x}{a}+2\left(\frac{\alpha}{\gamma}\right)^2\cos^2\frac{\pi x}{a}-\left(\frac{k}{\gamma}\right)^2\sin^2\frac{\pi x}{a}\right] \tag{14}$$

Here the subscript 1 has been dropped from the coefficients k_1, γ_1, and α_1 for simplicity, as these coefficients have the same value with respect to either of the two similar wave guides.

The condition for the absence of a backward wave is that B_1 be zero, that is,

$$2\left(\frac{\alpha}{\gamma}\right)^2\cos^2\frac{\pi x}{a}=\left[2+\left(\frac{k}{\gamma}\right)^2\right]\sin^2\frac{\pi x}{a} \tag{15}$$

that is,

$$\tan\frac{\pi x}{a}=\frac{\alpha}{\gamma}\sqrt{\frac{2}{2+\left(\frac{k}{\gamma}\right)^2}} \tag{16}$$

In order to remove the dependent variable x from its trigonometric form and isolate it on the left hand side of the equation, Equation 16 may be rearranged and expressed in the form

$$x=\frac{a}{\pi}\tan^{-1}\frac{\alpha}{\gamma}\sqrt{\frac{2}{2+\left(\frac{k}{\gamma}\right)^2}} \tag{16A}$$

For a numerical example, take the case where the operating frequency is such that the angle θ is 45 degrees, as this case gives simple figures and is a practical case as well.

Then

$$\frac{\alpha}{\gamma}=\frac{\pi}{a\gamma}=\frac{\pi}{a}\cdot\frac{\lambda_G}{2\pi}=\frac{\lambda_G}{2a}=\tan\theta=1 \tag{17}$$

and

$$\frac{k}{\gamma}=\frac{\lambda_G}{\lambda_0}=\sec\theta=\sqrt{2} \tag{18}$$

Substituting the values from Equations 17 and 18 into Equation 16 gives

$$\tan\frac{\pi x}{a}=\sqrt{\frac{2}{2+2}}=\frac{\sqrt{2}}{2}=0.707 \tag{19}$$

from which

$$\frac{\pi x}{a}\doteq 0.61 \text{ radians} \tag{20}$$

$$\frac{x}{a}\doteq 0.194 \tag{21}$$

$$x\doteq 0.194a \tag{22}$$

From this calculation it follows that the coupling hole in the case of the numerical example is to be placed with its center approximately one-fifth of the way from one narrower wall of the wave guide to the other narrower wall. When the hole is so placed, the backward wave in the excited wave guide is of minimum amplitude while substantially only a forward wave remains.

The foundation for applicant's extension of the theory to the case of a thick common wall lies in a recognition that the coupling hole in the thick wall may be regarded as the space within a hollow-pipe wave guide oriented at right angles to the exciting rectangular wave guide and is capable of being excited in two different modes simultaneously by a transverse electric wave in the rectangular wave guide. One of these excited modes is of the transverse electric type and the other is of the transverse magnetic type. Considerations of known principles of mode conversion show that the transverse electric mode in the coupling wave guide is excited substantially entirely by the magnetic components of the exciting wave, and the transverse magnetic mode substantially entirely by the electric component. Each wave so excited, in turn excites a wave in the second rectangular wave guide, each such wave traveling both forward and backward from the point of coupling. Interference between the latter two waves occurs in the second rectangular wave guide. This interference exhibits itself in amplitude differences between the forward and backward waves. In the extreme cases, either the backward wave or the forward wave may be canceled out or substantially suppressed.

A thin common wall with a coupling hole therethrough, as in the case already treated, constitutes a coupling wave guide of relatively short length, whereas when the wall is made thicker, the coupling line is longer. In the typical case there is not sufficient room for any coupling hole except it be relatively small in diameter compared to a wavelength at the operating frequency. Usually the hole will be so small that the cut-off frequency of the hole when regarded as a wave guide of infinite length is greater than any of the operating frequencies used. Therefore, the coupling wave guide theoretically will not support a traveling wave but will contain only a standing wave with amplitude attenuated exponentially with distance along the longitudinal axis of the coupling wave guide. Practically, of course, the coupling wave guide is not of infinite length and does support a traveling wave or it could not couple together the associated rectangular wave guides. The approximate theory herein used is found nevertheless to give usable practical results. Thus, if s be used to denote the thickness of the plate, which is then the length of the coupling wave guide, and A is the attenuation factor, we may define a coupling factor L as follows:

$$L=e^{sA} \tag{23}$$

The transverse magnetic mode will have one value of attenuation factor, which may be designated A_H, while the transverse electric mode will have another value of attenuation factor, A_E. Accordingly, the two components will have different coupling factors which may be designated L_H and L_E, respectively, defined by the following expressions:

$$L_H=e^{sA_H} \tag{24}$$

$$L_E=e^{sA_E} \tag{25}$$

The effect of attenuating the respective field terms of Equations 10 by passing the fields through the hole in the thickened coupling plate may be expressed by dividin each magnetic field term by L_E and each electric field term by L_H with the following results:

$$A_1'=\frac{j\gamma P}{ab}\left(\frac{2}{L_E}\sin^2\pi\frac{x}{a}+\frac{2}{L_E}\frac{\alpha^2}{\gamma^2}\cos^2\pi\frac{x}{a}-\frac{1}{L_H}\frac{k^2}{\gamma^2}\sin^2\pi\frac{x}{a}\right) \quad (26)$$

$$B_1'=\frac{j\gamma P}{ab}\left(-\frac{2}{L_E}\sin^2\pi\frac{x}{a}+\frac{2}{L_E}\frac{\alpha^2}{\gamma^2}\cos^2\pi\frac{x}{a}-\frac{1}{L_H}\frac{k^2}{\gamma^2}\sin^2\pi\frac{x}{a}\right) \quad (27)$$

The introduction of the coupling factors L_H and L_E modifies the position in which the coupling hole must be placed in order to suppress the backward wave and also modifies the amplitude of the forward wave.

By selection of a favorable value of the thickness of the common wall, the coupling between the two wave guides may be made substantially independent of the operating frequency over a considerable range of frequencies centered about a specified frequency in the operating range. In other words, the first derivative of A_1' may be made to vanish at the above-mentioned specified frequency by proper selection of the wall thickness. The actual value of s to secure the desired result is usually best found by substitution of numerical values into Equation 26 until a value of s is found which results in a maximum value of A_1'.

The appearance of a maximum value of A_1', or what is equivalent, the vanishing of the first derivative of A_1' depends upon a balancing of two tendencies, both of which arise from the frequency dependence of γ and k. Both γ and k increase in numerical value with increasing frequency. The factor γ occurs outside the brackets in Equation 26 and both γ and k occur in the terms inside the brackets.

For the hole locations usually found of interest in constructing directional couplers in accordance with the invention, the term outside the brackets increases with increasing frequency while the terms inside the brackets decrease with increasing frequency. The net result in the structure with a negligibly thin common wall is found to be a decrease in coupling with increasing frequency.

Taking into account the coupling factors L_H and L_E in the structure with the thick common wall, both L_H and L_E decrease with increasing frequency with the result that these factors tend to increase the terms inside the brackets as the frequency increases. By proper choice of thickness s of the common wall, values of L_H and L_E may be secured which at a particular frequency cause the rate of decrease of the terms inside the brackets to equal the rate of increase of the coefficient outside the brackets. The result is a zero rate of change of coupling with frequency at one frequency with a fairly constant coupling over a wide band of frequencies.

A particularly desirable arrangement is one in which the frequency of zero rate of change in the coupling is located between the frequency of maximum directivity of a single coupling hole on the one hand and the frequency for which the coupling holes have quarter wavelength spacings on the other hand.

For circular coupling holes the coupling wave guides are cylindrical. The attenuation factors A_H and A_E are well known in the theory of evanescent wave guide modes to be expressible as

$$A_H=\sqrt{\left(\frac{\omega_{cH}}{c}\right)^2-\left(\frac{\omega}{c}\right)^2} \quad (28)$$

$$A_E=\sqrt{\left(\frac{\omega_{cE}}{c}\right)^2-\left(\frac{\omega}{c}\right)^2} \quad (29)$$

in nepers per centimeter, where ω_{cH} is 2π times the cut-off frequency for the transverse magnetic mode, ω_{cE} is 2π times the cut-off frequency for the transverse electric mode, and c is the velocity of propagation of electromagnetic waves in free space in centimeters per second.

In an embodiment similar to that shown in Fig. 1, and which has been successfully operated, the wave guides **10, 11**, of rectangular cross-section are each 1.59 inches by 0.795 inch. The coupling plate **12** is 0.181 inch thick and has 24 coupling holes on each side of the center line. The coupling holes are each centered 0.29 inch from the nearest side wall of the rectangular wave guide. The coupling holes are centered at uniform intervals of 0.573 inch along the length of the coupling plate. The holes are of graded diameters as follows:

Position of hole	Diameter, inches	Reference character
1st and 24th	0.333	13
2nd and 23rd	0.4465	14
3rd and 22nb	0.504	15
4th thru 21st	0.521	16

The distance x_0 is 0.182 times the width a of the rectangular wave guide. The over-all length of the coupling plate is 14.75 inches.

In the above-described embodiment, the calculated cut-off frequency of the wave guide of rectangular cross-section is 3710 megacycles per second.

The calculated frequency of maximum directivity in a single hole due to its spacing of 0.182 a from the side wall is 5975 megacycles per second.

The calculated frequency of maximum directivity due to the uniform spacing of the holes at intervals of 0.573 inch apart along the length of the coupling plate is 6350 megacycles per second.

The calculated frequency of maximum coupling due to the effect of the thickness of 0.181 inch in the coupling plate is approximately 6200 megacycles per second.

The measured minimum directivity observed over a frequency band extending from 5925 to 6425 megacycles per second is 46 decibels. It is possible that this minimum value of directivity holds good over an even wider band but the measurements were not extended beyond the limiting frequencies stated.

The measured coupling between the exciting wave guide and the excited wave guide for the wave propagated in the forward direction in the latter wave guide is 10 decibels. The measured maximum variation from uniform 10-decibel coupling over the frequency band from 5925 to 6425 megacycles per second is 0.1 decibel.

The invention is not to be construed as limited to the particular embodiments, arrangements, or details disclosed herein.

What is claimed is:

1. A directional coupler comprising two lengths of hollow pipe wave guide of rectangular cross section having wide and narrow transverse cross sectional dimensions a and b, respectively, said guides having equal phase constants γ and equal attenuation constants α, said guides being physically disposed one to the other so as to share a common wide wall of width a, said common wall having a thickness s and having at least one coupling aperture therethrough for communication between said guides, said aperture having dimensions small compared to a wavelength at any operating frequency for said guides, said aperture being located a distance x from one of said narrow walls, the thickness s of said common wall having a value providing a maximum value for A_1' in the expression

$$A_1'=\frac{j\gamma P}{ab}\left\{\frac{2}{e^{sA_E}}\sin^2\pi\frac{x}{a}+\frac{2\alpha^2}{e^{sA_E}\gamma^2}\cos^2\pi\frac{x}{a}-\frac{k^2}{e^{sA_H}\gamma^2}\sin^2\pi\frac{x}{a}\right\}$$

wherein A_1' is the relative amplitude of the wave that is excited in one of said guides by an impressed wave in the other of said guides propagating in the same direction, A_E and A_H are the attenuation factors for transverse elec-

tric and magnetic modes, respectively, passing through said coupling aperture, P is a multiplier which determines the magnitude of an electric moment of an equivalent electric dipole conceived of as being set up at the position of the coupling aperture, and wherein k is the phase constant in free space of any operating frequency of said directional coupler.

2. A directional coupler comprising two hollow pipe wave guides of rectangular cross section having wide and narrow transverse cross sectional dimensions a and b, respectively, said guides having equal phase constants γ and equal attenuation constants α, said guides being disposed so as to extend in a common direction with a wide dimensioned wall of one of said guides being in a parallel, adjacent and facing relation to a wide dimensioned wall of the other said guide, at least one wave guiding channel disposed orthogonally to said common direction for coupling said two guides one to the other through said adjacent wide walls, said orthogonal channel having cross sectional dimensions small compared with a wavelength of the operating frequency, said orthogonal channel being coupled to said guides at a distance x from a lateral edge of each of said adjacent wide walls, the length s of said orthogonal channel having a value providing a maximum value for A_1' in the expression

$$A_1'=\frac{j\gamma P}{ab}\left\{\frac{2}{e^{sA_E}}\sin^2\pi\frac{x}{a}+\frac{2\alpha^2}{e^{sA_E}\gamma^2}\cos^2\pi\frac{x}{a}-\frac{k^2}{e^{sA_E}\gamma^2}\sin^2\pi\frac{x}{a}\right\}$$

wherein A_1' is the relative amplitude of the wave that is excited in one of said guides by an impressed wave in the other of said guides propagating in the same direction, A_E and A_H are the attenuation factors for transverse electric and magnetic modes, respectively, passing through said orthogonal channel, P is a multiplier which determines the magnitude of an electric moment of an equivalent electric dipole conceived of as being set up at the position of the orthogonal channel, and wherein k is the phase constant in free space of any operating frequency of said directional coupler.

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