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DIRECTIONAL COUPLERS

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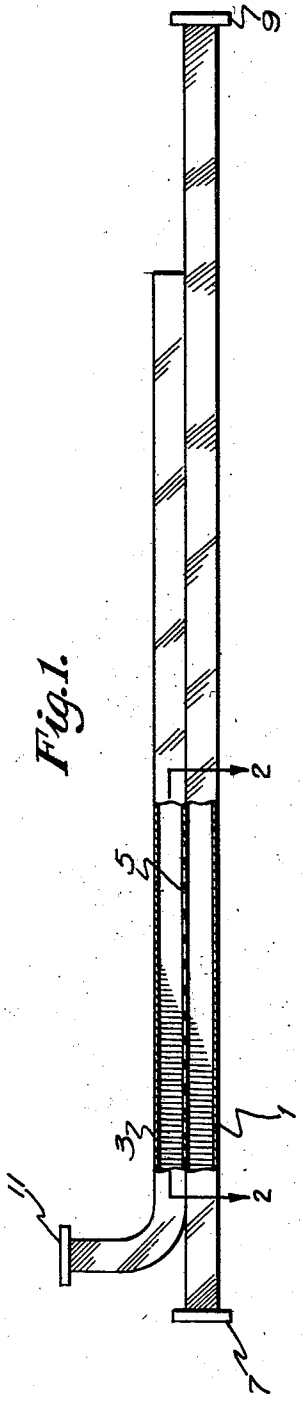


Fig. 1.

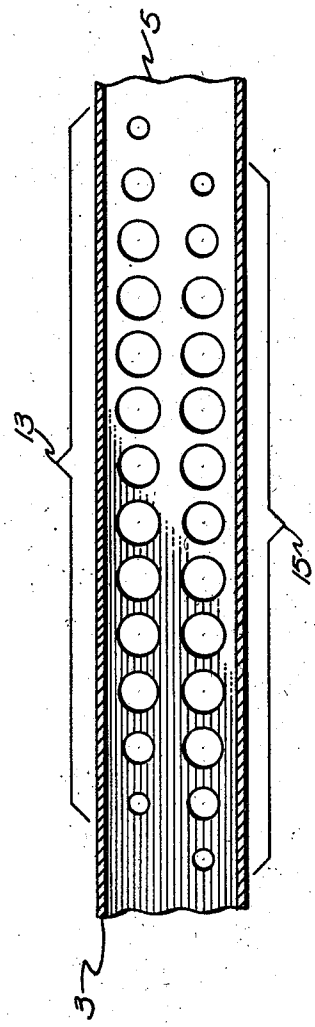


Fig. 2.

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DIRECTIONAL COUPLERS

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This invention relates to improvements in directional couplers, and more particularly to directional couplers of the waveguide type, in which a main waveguide or primary waveguide is coupled to a branch or auxiliary waveguide by means of one or more arrays of coupling elements such as apertures in a common wall that separates the two waveguides.

Directional couplers are used in the microwave radio art for various purposes such as power monitoring, measurements, isolation, and other applications which require that power flowing in one direction in the main guide will induce a flow of power only in a corresponding direction in the auxiliary guide. One of the measures of the quality of a directional coupler is its ability to discriminate between power flowing in one direction in the main guide and power flowing in the other direction, i. e. the ratio of the power induced in the auxiliary guide in the desired direction to that induced in the opposite direction, by power flowing in one direction in the main guide. This ratio is called the directivity, and is usually expressed in decibels.

Another characteristic that specifies the performance of a directional coupler is its attenuation. This is the ratio of the power induced in the desired direction in the auxiliary guide to the power in the main guide that induces it. Often it is desirable that the directivity be relatively high, and the attenuation be nearly constant, throughout a substantial range of operating frequencies. The frequency range over which the directivity and attenuation remain within specified tolerances may be regarded as the bandwidth of the coupler.

The principal object of this invention is to provide an improvement in directional couplers whereby there is attained a directivity that is substantially greater than that of similar prior art directional couplers.

Another object is to achieve the above-mentioned improvement in directivity without any corresponding increase in the complexity of design or construction of the directional coupler, and without any sacrifice in bandwith or constancy of attenuation.

The invention will be described with reference to the accompanying drawing, wherein:

Fig. 1 is a view in elevation, partly in section, of a directional coupler constituting a presently preferred embodiment of the invention, and

Fig. 2 represents a section along the plane II—II of the structure of Fig. 1.

Directional couplers of the type to which the present invention relates generally comprise two waveguides that are joined throughout a portion of their lengths to provide a common wall, as shown in Fig. 1, and some kind of coupling means such as a plurality of apertures in the common wall for transferring wave energy from one guide to the other. In the structure of Fig. 1 the main waveguide 1 and the auxiliary waveguide 3 are both of rectangular cross section, with their respective adjacent broad sides joined to form a common wall portion 5. The main guide 1 is provided at its ends with fittings 7 and 9 for connection with external apparatus such as a source and a load, respectively, and one end of the auxiliary guide 3 has a similar fitting 11 for connection to

other apparatus, for example a power measuring instrument. The other end of the guide 3 is terminated with a resistive load to minimize reflections therefrom.

One of the simplest arrangements for coupling the waveguides in a coupler like that of Fig. 1 consists of two identical holes in the common wall, spaced apart along the longitudinal axis by a distance equal to one quarter the guide wavelength at a specified operating frequency. When power is flowing in the main waveguide, a small part of it couples through each of the holes, exciting waves in the auxiliary guide that propagate in both directions from each hole. At the particular frequency where the spacing between the holes is one-quarter wavelength, the waves in the auxiliary guide traveling in the direction opposite to the power flow in the main guide cancel each other, while those traveling in the same direction as those in the main guide reinforce each other.

The directivity of the two-hole coupler deteriorates rapidly as the operating frequency departs from that for which the coupler is designed; i. e. the bandwidth of such a coupler is narrow. Considerable improvements in bandwidth may be obtained by modifying the design of the coupling arrangement to use a larger number of holes, with the hole sizes distributed in such a way as to form the equivalent of an array of overlapping two-hole couplers, spaced at quarter-wavelength intervals along the axis. The simplest array of this sort consists of three coupling elements or holes spaced at quarter-wave intervals, with the center one designed to couple twice as much voltage into the auxiliary guide as each of the end coupling elements. This gives the effect of two identical two-hole couplers, spaced apart one-quarter wavelength.

Similarly a four-hole coupler can be designed as an array of two overlapping three-hole arrays, and so on. Distributions of this kind are known as binominal arrays, because the voltages required to be coupled through successive holes in the series are proportional to the coefficients of a binomial expansion whose order is one less than the number of holes. Directional couplers using binomial arrays are described in U. S. Patent 2,562,281. The directivity of a binomial array remains reasonably high throughout a frequency band whose width depends upon the number of coupling elements. However, the directivity decreases steadily as the operating frequency departs from the design frequency.

A more efficient array, from the standpoint of the number of holes required to achieve a specified minimum directivity over a given frequency band, is the Tschebyscheff type, so named because the coupling amplitudes of the successive holes in the series are proportioned so that the amplitude of the backward wave induced in the auxiliary waveguide oscillates as a function of frequency in a manner corresponding to the variations of a Tschebyscheff polynomial whose order is one less than the number of coupling holes. Tschebyscheff polynomials are functions whose values oscillate between limits of $+1$ and -1 as the value of the independent variable is varied from -1 to $+1$. The number of oscillations over this region depends upon the order of the polynomial.

By expressing the amplitude of the backward wave coupled into the auxiliary guide in the form of a Tschebyscheff polynomial of the order corresponding to the number of coupling holes, less one, and choosing units to make the ranges from -1 to $+1$ correspond to the desired bandwidth and the permissible variation in directivity, respectively, the required coupling amplitudes may be solved for. The use of the basic Tschebyscheff distribution in directional couplers is described in the Proceedings of the I. R. E. volume 39, page 291 (March 1951) by F. Bolinder.

In cases where relatively low attenuation is required together with high directivity, it is found that the basic

Tschebyscheff array becomes impractical because it must be too long, and the ratio of the largest holes to the smallest is too great. This difficulty can be alleviated by overlapping several basic arrays, thereby making the overall coupling region shorter and making the required hole sizes more nearly uniform. Such overlapping decreases the attenuation in accordance with the number of basic arrays used without adversely affecting the directivity. For still lower attenuation, two or more arrays may be placed side by side in the common wall between the guides, each array being overlapped. This arrangement provides the desired lower attenuation but retains substantially the same directivity as the basic array. A double row triply overlapped Tschebyscheff coupler of this design is described in the March-April 1952 issue of the Hewlett-Packard Journal, published by the Hewlett-Packard Company, Palo Alto, California.

According to the present invention, the directivity of multiple-row couplers is materially improved without any increase in attenuation or complexity of structure, and with only a small increase in length, by spacing the rows of coupling elements apart longitudinally. Referring to Fig. 2, the coupling arrangement of the illustrated embodiment of the invention comprises two rows **13** and **15** of circular holes arranged side by side in the wall **5** and displaced longitudinally with respect to each other by one quarter the guide wavelength at the center of the frequency band over which the coupler is to be used. Each of the rows **13** and **15** is designed as a triply overlapped Tschebyscheff array. The center line of each row is located about one quarter of the guide width from the respective edge of the wall **5** to minimize variations, as a function of frequency, of the couplings provided by the individual holes.

In a typical coupler, designed for operation over the frequency range designated in the art as "X band," the pertinent dimensions are as follows:

Waveguides, 1"×½"×.050" wall

Coupling hole diameters in each row, starting with the center hole and proceeding either way,

.282
.283
.233
.275
.253
.210
.140

Lateral spacing of each row from the respective edge of the common wall, .225"

Longitudinal spacing between holes, .380"

Longitudinal displacement between the two rows, .380"

The average directivity of the described coupler, over the operating frequency band, is about 6 db. higher than that of a similar coupler wherein the rows of coupling elements are not displaced longitudinally. This improvement in performance is effected without any increase in the difficulty of designing or fabricating the device.

Although the invention has been described as embodied in a specific design of directional coupler, it may be employed in any multiple-row type of coupling array with similar advantage.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A directional coupler comprising a main waveguide and an auxiliary waveguide, said waveguides being parallel and adjacent throughout a portion of their lengths to provide a coupling region, a plurality of substantially identical rows of coupling elements in said region, each of said rows extending along a respective line parallel to the longitudinal axes of said guides, the elements of each of said rows being spaced apart longitudinally at equal intervals of substantially one quarter guide wavelength at the center of the frequency band throughout which the device is to operate, whereby each row of elements constitutes a directional coupling array, said rows being displaced longitudinally with respect to each other by a distance equal to said longitudinal intervals between coupling elements.

2. A directional coupler comprising two rectangular waveguides having a common broad wall, a first directional coupling array comprising a row of apertures in said wall disposed at equal intervals of substantially one quarter the guide wavelength at the center of the frequency band throughout which the device is to operate along a first line parallel to the longitudinal axis of said wall, said apertures having relative proportions such as to provide an overlapped Tschebyscheff array, and a second coupling array identical with said first array but disposed along a second line on the opposite side of said axis from said first line, each of said lines being spaced laterally from the respective edge of said broad wall by a distance of substantially one-quarter the width of said wall, said arrays being displaced longitudinally with respect to each other by a distance equal to said longitudinal interval between apertures.

3. A directional coupler comprising two waveguides having a common wall, a first directional array of coupling elements, said array being substantially longer than one wavelength at the lowest frequency of operation and extending along a line parallel to but laterally spaced from the longitudinal axis of symmetry of said common wall, and a second directional array of coupling elements substantially identical to said first coupling array but disposed along a second line laterally spaced from said longitudinal axis on the other side from said first line, said second array being longitudinally displaced with respect to said first array by a distance less than the length of one of said arrays, the longitudinal displacement between said coupling arrays being substantially one-quarter the guide wavelength at the middle of the frequency band throughout which the device is to operate.

4. A directional coupler comprising a main waveguide and an auxiliary waveguide, said waveguides being joined throughout a portion of their lengths to provide a common wall, a plurality of substantially identical rows of apertures in said common wall, each of said rows extending along a respective line parallel to the longitudinal axis of said wall, said lines being spaced apart laterally of said wall, the apertures in each of said rows being spaced apart longitudinally at equal intervals of substantially one-quarter wavelength at the center of the band of operating frequencies, said rows being displaced longitudinally with respect to each other by a distance substantially less than the lengths of said rows, the longitudinal displacement between said rows is substantially one-quarter the guide wavelength at the center of the frequency band throughout which the device is to operate.

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