

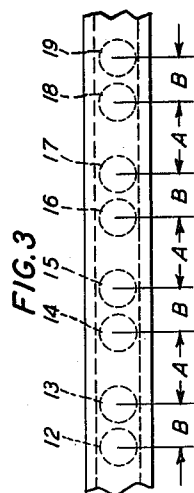
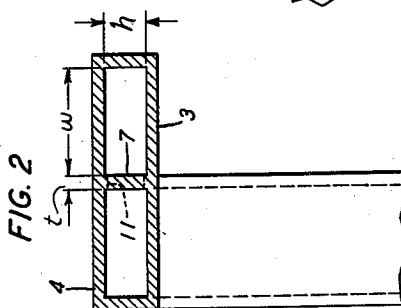
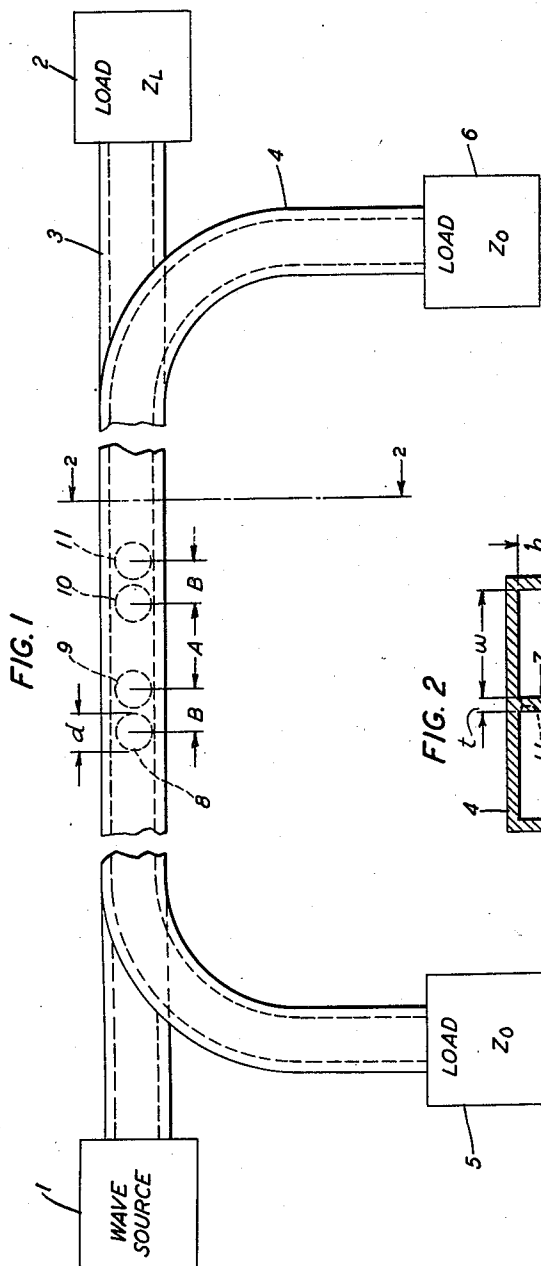
Feb. 13, 1951

J. T. BANGERT ET AL
DIRECTIONAL COUPLER

2,541,910

Filed Sept. 18, 1947

2 Sheets-Sheet 1



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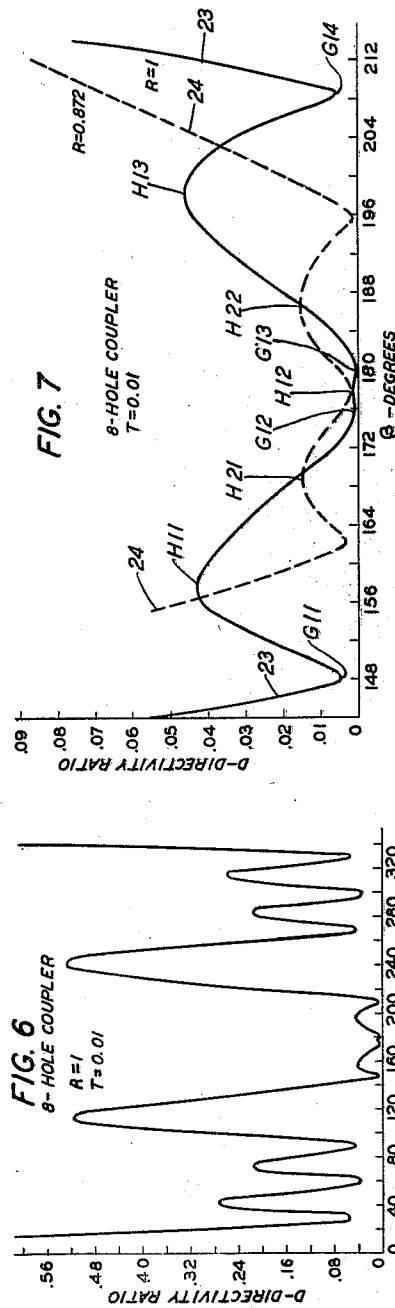
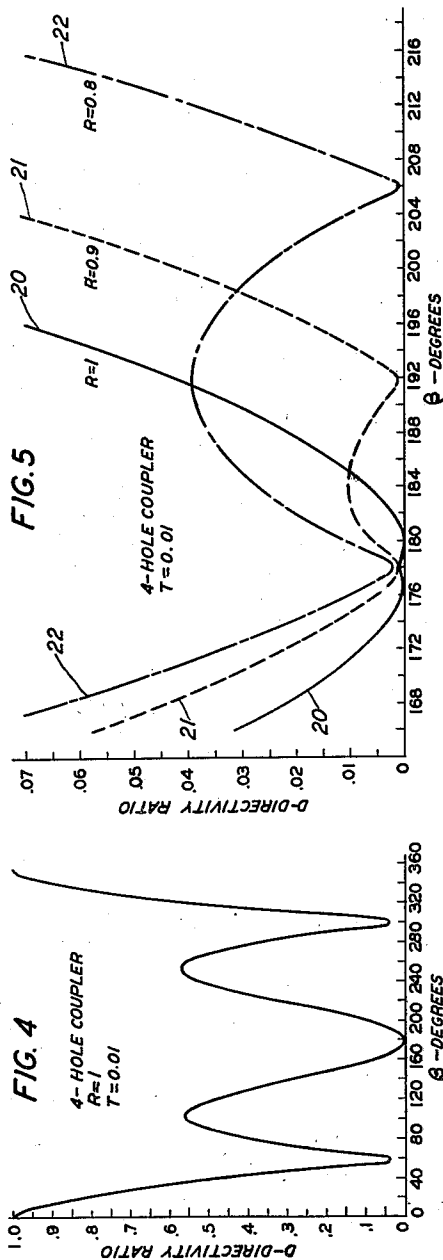
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UNITED STATES PATENT OFFICE

2,541,910

DIRECTIONAL COUPLER

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6 Claims. (Cl. 178-44)

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This invention relates to wave transmission and more particularly to directional couplers.

The principal object of the invention is to increase the frequency band over which a low directivity ratio is obtainable in a directional coupler. Another object is to reduce the direct loss. Other objects are to simplify the construction of such a coupler and to reduce the manufacturing cost.

A directional coupler is a device associated with a transmission line for sampling separately the forward and the backward waves in the line. In its simplest form such a device comprises an auxiliary transmission line with two equal coupling links to the main transmission line spaced a quarter wavelength apart. The currents flowing in one direction in the auxiliary line will be additive for waves propagated in one direction in the main line but will cancel for waves traveling in the opposite direction. The transmission lines may be open wire lines, coaxial lines, or wave guides and the coupling links may be probes, loops or apertures.

In order to measure accurately backward waves of small amplitude a small directivity ratio is required for the directional coupler. However, in a two-link coupler this ratio is satisfactorily small over only a narrow band of frequencies. To make the directional coupler operable over a wider band the number of coupling links may be increased. For example, in a paper entitled "Directional Couplers" published in the Proceedings of the I. R. E., vol. 35, No. 2, pages 160 to 165, February 1947, W. W. Mumford describes directional couplers which employ more than two coupling links. The links have equal spacings of a quarter wavelength but their transmission factors are tapered according to the coefficients of the binomial expansion.

In accordance with the present invention the frequency band of a directional coupler is widened by employing a plurality of pairs of substantially equal coupling links, with the displacement A between pairs greater than the intra-pair spacing B between the links forming a pair. For a minimum directivity ratio throughout the band the displacement factor R, which is the ratio of A to 2B, is approximately unity. However, the band may be further widened by reducing this ratio. For an eight-link coupler an optimum ratio is approximately 0.92.

When the directional coupler comprises wave guides connected by coupling holes, it is easier to achieve a low value of direct loss with the multiple-pair type of coupler than with one of

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the binominal-coefficient type having the same number of holes. This is because the direct loss is a function of the total area of the holes. In the multiple-pair type of coupler all of the holes may have a diameter as large as the width of the guide but in the binominal coupler only the central hole may be this large.

In practice it has been found that a number of equal coupling links are easier to construct than a number of links in which the transmission factor is required to be tapered in some manner from link to link. The simpler construction reduces the cost of manufacture and makes it easier to build a directional coupler to fit given specifications.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 shows a transmission system incorporating a four-link directional coupler;

Fig. 2 is a cross-sectional view of the directional coupler of Fig. 1 taken along the line 2-2;

Fig. 3 shows the central fragment of the directional coupler of Fig. 1 modified in accordance with the invention to employ eight coupling links;

Fig. 4 is a curve showing the directivity ratio D for the four-link coupler of Fig. 1 plotted against the intra-pair phase shift angle β over a range of 360 degrees;

Fig. 5 presents a family of curves showing the D- β characteristic of the four-link coupler for three values of the displacement factor R;

Fig. 6 is the D- β characteristic of the eight-link coupler of Fig. 3 plotted over a 360-degree range; and

Fig. 7 gives the D- β characteristics of the eight-link coupler for two values of R.

In the four-link directional coupler shown in Figs. 1 and 2 electromagnetic waves from the source 1 are fed to a load 2 of arbitrary impedance Z_L through a main transmission line 3 of characteristic impedance Z_0 . An auxiliary transmission line 4, also of characteristic impedance Z_0 , is longitudinally juxtaposed to the line 3 for a portion of its length. The line 4 is terminated at one end in a load 5 and at the other end in a load 6, each of impedance Z_0 . As shown more clearly in Fig. 2 the lines 3 and 4 are wave guides of rectangular cross-section and one of the narrower sides 7 is common to both. The guides 3 and 4 are electrically connected by two pairs of coupling links, 8, 9 and 10, 11, in the form of circular holes of the same diameter in the common wall 7.

Fig. 3 shows a modified form of the directional coupler of Figs. 1 and 2 in which the two pairs of coupling links are increased to four pairs, constituted by the holes 12 to 19 in the common wall 7. In other respects the eight-hole coupler is the same as the one shown in Figs. 1 and 2.

If the impedance Z_L of the load 2 does not match the impedance Z_0 of the line 3, part of the forward wave from the source 1 is reflected as a backward wave traveling toward the left. In an ideal directional coupler the portion of the forward wave which enters the auxiliary line 4 through the holes in the wall 7 will all be dissipated in the load 6 and none will reach the load 5. Also, the entire portion of the backward wave which enters the line 4 will be dissipated in the load 5, with none reaching the load 6. If, for example, the loads 5 and 6 are power-indicating devices the power associated with each of these waves may be separately measured.

The accuracy of such measurements depends upon a characteristic of the coupler which may be termed its directivity ratio D . This is defined as the square root of the ratio of the power received at the load 5 to the power received at the load 6 when power is introduced into the line 3 from the source 1, assuming that the lines 3 and 4 are perfectly terminated. In an ideal coupler D is zero.

An expression for evaluating the directivity ratio D for the four-hole coupler of Figs. 1 and 2 will now be presented, based upon the following additional assumptions:

1. The energy in the auxiliary line 4 is small compared with that in the main line 3.
2. The phase shifts in the coupling holes 8 to 11 are identical.
3. The coupling holes 8 to 11 have the same orifice transmission factor T , defined as the amplitude ratio of transmission therethrough.
4. The lines 3 and 4 are lossless and have the same phase velocity.

With these assumptions

$$D = \frac{1}{2} \left| \cos \theta_a + \cos \theta_b - 2T(\sin \theta_a + 3 \sin \theta_b) + j6T(\cos \theta_a + \cos \theta_b) \right| \quad (1)$$

where the bars indicate that the absolute magnitude is taken,

$$\theta_a = \beta R \quad (2)$$

$$\theta_b = \beta(R+1) \quad (3)$$

$$R = \frac{A}{2B} \quad (4)$$

$$\beta = \frac{720B}{\lambda_g} \text{ degrees} \quad (5)$$

and λ_g is the wave guide wavelength. As shown in Fig. 1, A is the linear distance between the centers of adjacent holes, such as 9 and 10, of adjoining pairs and B is the linear distance between the center of the holes, such as 8 and 9, comprising a pair. The factor T may be found from the formula

$$\frac{1}{T} = \frac{4.2 w^3 h}{\lambda_g d^3} + 32 \frac{t}{d} \sqrt{1 - (1.71d/\lambda)^2} \quad (6)$$

where λ is the free space wavelength and, as shown in Figs. 1 and 2.

d = diameter of hole

h = wave guide height

t = thickness of the wall 7

w = wave guide width

Formula 6 is based on the transmission through an orifice with a thin wall plus the loss in a cir-

cular wave guide of length t operating below cut-off in the TE_{11} mode. It has been found to check experimental data to within two decibels.

Fig. 4 is a computed characteristic showing the directivity ratio D plotted against the intra-pair phase shift angle β , over a complete angular cycle, for the four-hole directional coupler of Figs. 1 and 2, using Formula (1). The displacement factor R is unity, which, in accordance with Equation 4, means that the displacement A is equal to twice the intra-pair spacing B . The orifice transmission factor T is 0.01. It is seen that the directivity ratio D is a minimum in the neighborhood of 180 degrees and this is the region that is ordinarily used. There are, however, two other regions, with centers at approximately 60 and 300 degrees, which might be used although they are somewhat narrower in angular band width and the minimum values of D are higher than in the preferred region at 180 degrees. At zero and 360 degrees the ratio D becomes unity, which is the limiting case of no discrimination to the direction of travel of the waves in the line 3.

Fig. 5 presents a family of curves showing the directivity ratio D as a function of the intra-pair phase shift angle β , with the displacement factor R as the third parameter. Only the region of most interest, between 168 and 216 degrees, is shown. The orifice transmission factor T is 0.01 in each case. The solid-line curve 20 shows, to a considerably enlarged scale, the central portion of the curve of Fig. 4, for which R is unity. There are two points where D is a minimum, one at 176 and the other at 180 degrees.

The angular band width of the D - β characteristic may be increased, at the expense of a higher maximum directivity ratio within the band, by decreasing the displacement factor R . For example, curve 21 of Fig. 5 shows the characteristic for an R of 0.9 and curve 22 for an R of 0.8. As the value of R is reduced from unity it is seen from the curves that the left minimum shifts from 176 to 178 degrees and stays almost fixed at that point, that the right minimum moves to the right, to 192 degrees for curve 21 and to 206 degrees for curve 22, thus widening the band, and that the intermediate maximum value of D increases in height, being approximately 0.01 for curve 21 and 0.04 for curve 22.

Any D - β curve can, of course, be converted to a directivity-frequency curve by assigning a value to B , the intra-pair spacing. The resulting curve will have the same general shape as the original and the position of the low frequency minimum will be a direct function of the intra-pair spacing B .

The formula for the determination of the directivity ratio D for the eight-hole directional coupler of Fig. 3, making the same assumptions as in Formula 1, is

$$D = \frac{1}{2} \left| [MN - PT(10M+8) - 4MT \sin \theta_b + j14MNT] \right| \quad (7)$$

$$M = \cos(\theta_a + \theta_b) \quad (8)$$

$$N = \cos \theta_a + \cos \theta_b \quad (9)$$

$$P = \sin \theta_a + \sin \theta_b \quad (10)$$

and θ_a , θ_b , R and T have the same significance as in Formula 1.

Fig. 6 is a curve showing the variation of the directivity ratio D of an eight-hole coupler over a complete cycle of the intra-pair phase shift angle β when the displacement factor R is unity and the orifice transmission factor T is 0.01. There are ten maxima and ten minima in the cycle and the curve is very nearly symmetrical

about a vertical axis at 178 degrees. The region in which β lies between 144 and 212 degrees is of greatest interest and this portion of the characteristic is reproduced on an enlarged scale as the solid-line curve 23 of Fig. 7.

In the eight-hole coupler, as the displacement factor R is reduced from unity the first minimum point G11 moves to the right, the second minimum G12 moves to approximately 178 degrees and remains fixed at that point, the third minimum G13 also moves to the right, the fourth minimum G14 moves to the right and out of the region of interest, the first maximum H11 moves to the right and decreases in height, and the second maximum H12 also moves to the right but increases in height. For all eight-hole couplers in which R is less than unity the second minimum, occurring at 178 degrees, is considered to be the basic one and therefore it is adjusted to fall at the desired frequency by a proper selection of the intra-pair spacing B.

The characteristic corresponding to an R of 0.872 is of particular interest and is shown as the broken-line curve 24 of Fig. 7. It is seen that the first two maxima H21 and H22 are equal in height and are considerably lower than the maxima H11 and H13 for curve 23. For a maximum allowable directivity ratio D equal to the height of the maxima H21 and H22, which is 0.016, the angular band width for an R of 0.872 is about 39 degrees, compared to a band of about 19 degrees obtainable for an R of unity. In this case the band width has been more than doubled by decreasing R from unity to 0.872 which, therefore, is an optimum value. For a four-hole coupler having the same maximum D in the band, for which R is 0.875, the angular band width is about 25 degrees. Therefore, in this case, increasing the number of holes from four to eight and using the optimum value of 0.872 for R has increased the band width by about 56 per cent.

The D- β characteristics shown in Figs. 4 to 7 were computed in accordance with the Formulas 1 and 7. However, measurements made on a number of directional couplers have shown that the actual curves obtained are much flatter over the band and more spread out than the ones shown. The measured curves are found to be in good agreement with the computed curves if the theoretical value of the displacement factor is increased by about five per cent. Therefore, the correct optimum value of the displacement factor R for the two equal maxima H21 and H22 shown in curve 24 of Fig. 7 is 0.872 plus five per cent, or approximately 0.92. That is, by Equation 4, the displacement A should be equal to approximately 1.84 times the intra-pair spacing B.

What is claimed is:

1. A directional coupler comprising a main transmission line, a longitudinally juxtaposed auxiliary transmission line, and four pairs of coupling links interconnecting said lines at longitudinally spaced intervals, all of said coupling links having substantially equal transmission factors and the ratio of the spacing between the centers of adjacent links of adjoining pairs to twice the spacing between the centers of the links comprising a pair being approximately equal to 0.92.
2. A directional coupler in accordance with claim 1 in which said auxiliary transmission line is terminated at each end in an impedance substantially equal to its characteristic impedance.
3. A directional coupler in accordance with claim 1 in which said coupling links have substantially equal phase shifts.
4. A directional coupler in accordance with claim 1 in which said transmission lines have substantially the same phase velocity.
5. A directional coupler in accordance with claim 1 in which said transmission lines are wave guides having a common side wall and said coupling links are holes in said common wall.
6. A directional coupler comprising two wave guides having a common side wall and four pairs of holes in said common wall at longitudinally spaced intervals, said transmission lines having substantially the same phase velocity and the ratio of the spacing between the centers of adjacent holes of adjoining pairs to twice the spacing between the centers of the holes comprising a pair being approximately equal to 0.92.

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