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# A Precision Directional Coupler Using Multi-Hole Coupling

DIRECTIONAL couplers have been used widely in wave guide applications for such purposes as monitoring power, measuring reflections, mixing, and for isolation of signal sources. All of these applications make use of the property that power flowing in one direction in the main branch of the coupler induces a power flow in only one direction in the auxiliary circuit.

A common type of directional coupler consists of two sections of waveguide bonded together physically and electrically coupled by one or more apertures common to both guides. Power entering the input arm of the coupler flows down the primary guide and divides at the coupling mechanism. The larger portion continues down the primary guide; the smaller portion is coupled into the auxiliary guide. Ideally, a uni-directional flow of power in the primary guide should couple into the auxiliary guide a flow of power that is also uni-directional. As a practical matter, some of the coupled power ordinarily flows in the reverse direction. The ratio of this forward to reverse power in the auxiliary guide is termed the "directivity" of the coupler.

The property of dividing power leads to the use of directional couplers in monitoring power levels that are greater than the range of convenient power-measuring equipment. For many applications and for measurement work especially, it is desirable that the power division or "coupling" be constant with frequency in order to reduce measurement error.

Directional couplers can be divided into two classes, depending upon whether they are to be used for monitoring power or for measuring the amplitude of small reflections. Power monitoring usually requires a coupling not tighter than 20 db and a directivity of only moderate value.

Couplers used for measuring reflections require tighter coupling and higher directivity than those used for power monitoring. Usually, a coupling tighter than 20 db and a directivity greater than 30 db are desirable. If small reflections are to be measured, even higher directivity is required. Heretofore, such high directivity has not generally been obtainable over a wide band when the coupling is tighter than 30 or 40 db because of imperfections in coupling mechanisms.

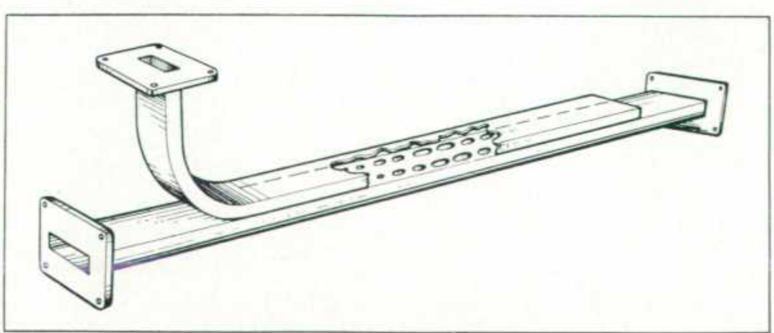

Fig. 1. *-hp- Multi-hole directional coupler.*

Two new couplers in 10 and 20 db values have been designed in the 8,200 to 12,400 megacycle range to provide constant cou-

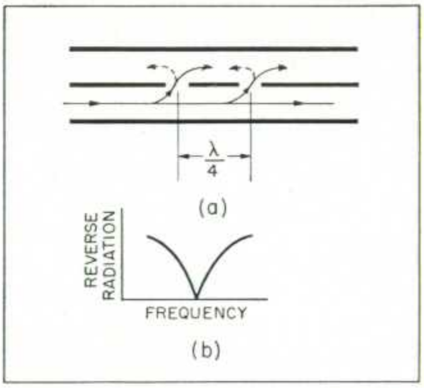


Fig. 2. *Cross-section (a) and directivity (b) of two-aperture coupler.*

pling over a wave guide range of frequencies and to provide a high directivity of at least 40 db even in couplers with as tight as 10 db coupling. The couplers consist of two wave guide sections bonded together along their broad faces. Coupling is obtained by a series of round holes placed in two rows along the adjacent faces (Fig. 1).

The action of the coupling mechanism can be described in terms of a basic coupling mechanism that consists of two identical holes (Fig. 2). If the holes are spaced one-quarter of a guide wavelength apart at some particular frequency, the coupler will exhibit high directional properties at that frequency. Power flowing down the primary guide couples through the holes, exciting in the auxiliary guide waves which propagate in both directions. Since the coupling holes are spaced one-quarter wavelength apart, the waves travelling in the reverse direction in the auxiliary guide are one-half wavelength out of phase with each other. Thus, the waves mutually cancel in the reverse direction. Waves travelling in the forward direction reinforce each other because the path lengths through either of the coupling holes are equal.

The two-hole coupling mechanism can be modified to obtain broadband operation by increasing the number of holes. With a larger number of coupling holes, a considerable variety of reverse radiation spectra can be obtained by varying the distribution of hole sizes. One distribution which has frequently been used is that in which the voltage coupling coefficients are made proportional to the coefficients of a binomial expansion of order equal to one less than the number of holes. This gives a reverse radiation spectrum which is equal to zero at the frequency $f_1$ where the spacing between holes is equal to a quarter of a guide wavelength and which is as flat as possible (for the given number of holes) in the neighborhood of this frequency. The directivity is very good in the immediate neighborhood of $f_1$ (which can be chosen to be in the center of the waveguide frequency band) but becomes steadily worse at higher and lower frequencies.

Another method for approximating zero over a band of frequencies is to obtain a reverse radiation spectrum that oscillates with equal ripple amplitude about zero over the desired frequency range in a Tschebyscheff manner. This method has the advantage that the maximum error is constant with frequency rather than a function of frequency as in the binomial example. This advantage is illustrated in Fig. 3 which shows a comparison of the Tschebyscheff and binomial approximations for arrays having equal numbers of holes equally spaced. In the design of these couplers, the equal ripple amplitude approximation was used by suitable selection of the coupling coefficients of the individual coupling holes.

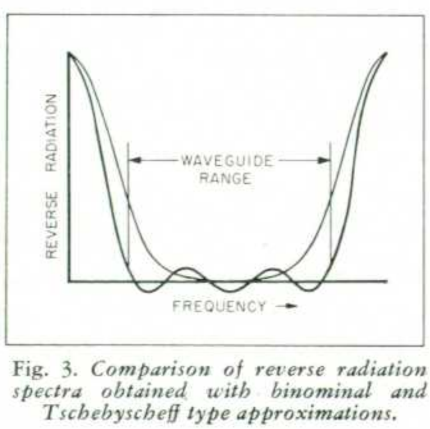


Fig. 3. *Comparison of reverse radiation spectra obtained with binominal and Tschebyscheff type approximations.*

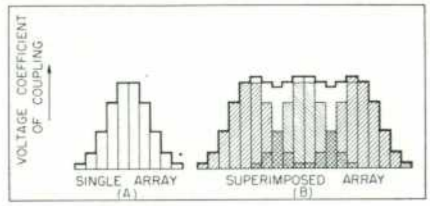


Fig. 4. *(a) Relative magnitude of voltage coefficient of coupling for single array; (b) method used to increase coupling by superimposing coefficients of three arrays.*

The amplitude of the ripple in the reverse radiation spectrum depends primarily on the total length L of the array of coupling holes. Once the length has been selected, the minimum permissible number of holes in the array is determined by the fact that the spacing between neighboring holes must be less than a half wavelength at the highest waveguide frequency if cancellation in the reverse direction is to occur. The maximum permissible number of holes is controlled by the fact that the spacing must not permit neighboring holes to overlap.

For a given directivity and forward coupling, the hole dimensions are determined by the length of the array and by the number of holes used. In the 20 db coupler, 10 holes are used in each of the two rows. The relation of the voltage coupling coefficients of the various holes is shown in Fig. 4(a).

The above methods were used to construct a 20 db coupling mechanism designed to have better than 50 db directivity. To make practical use of a directivity of this quality, it is necessary that reflections from the termination at the forward end of the auxiliary guide be unusually small. This requirement arises when using a directional coupler to measure the reflection coefficient of a device having small reflection. The reflection coefficient is measured by monitoring the power flowing in the forward direction in the primary guide and by measuring reflections from the unknown at the reverse end of the auxiliary guide.

When reflection from the main guide load is small, any significant reflection from the termination at the forward end of the auxiliary guide will obscure the reflections to be measured. The magnitude of reflections from the auxiliary termination combined with the radiation in the reverse direction by the coupling mechanism determine the minimum value of reflection that can be measured. Thus, to make available the full capabilities of the coupler, it has been necessary to develop an extremely low-reflection load. The VSWR of this load is less than 1.01 over the wave-guide frequency range.

Another important factor in the design of directional couplers is the constancy of coupling over the frequency range of a standard wave guide. The Bethe small hole theory shows that coupling as a function of frequency is dependent upon the location of the coupling holes across the width (y dimension) of the guide. The hole location for the couplers was determined from this theory for minimum variation of coupling with frequency and later modified slightly on the basis of experimental results. Less than $\pm$ 0.7 db deviation from the nominal 20 db figure is obtained over the waveguide range.

If the above design procedure for a 20 db coupler is extended to a 10 db coupler, two conflicting conditions arise. First, if the length of the array is limited to the length needed for the desired directivity, the sizes of the coupling holes become inconveniently large and overlapping will occur. Second, if the sizes of the central holes are held constant, it is found that increasing the number of holes increases the coupling by only a minor amount so that the array becomes impracticably long.

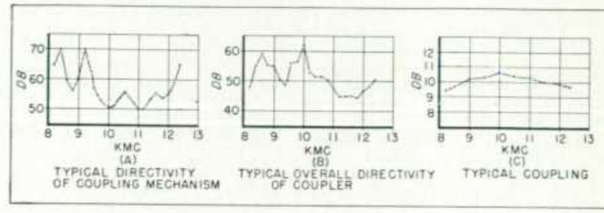


Fig. 5. *Characteristics of typical -hp- 10 db multi-hole coupler.*

These difficulties were overcome by designing a new array based on the following considerations. The voltage coupled into the auxiliary guide by an array is proportional to the area under the curve of voltage coupling coefficients of the individual holes plotted as in Fig. 4(a). If three such arrays are superimposed in the conventional staggered arrangement of Fig. 4(b), the resulting curve bounds an area three times as great as an individual array. The coupled voltage of the composite array is therefore three times as large as that of the individual array, corresponding to an increase in coupled power of 9.5 db.

The design for the 10 db coupler was obtained by superimposing three basic arrays in the above manner. However, if three arrays of 20 db coupling are superimposed, the resulting increase in coupled power of 9.5 db results in a composite array having only 10.5 db of coupling. Therefore, three 19.5 db arrays were used in obtaining the final 10 db design

Combining the three basic arrays in this manner does not cause deterioration in directivity. Theoretically, the voltage received at the reverse terminal of the auxiliary guide will, in the worst case, be 3.16 times as great as in the case of the 20 db coupler. However, the forward coupling is also 3.16 times as great as in the 20 db design. Thus, no worsening of directivity should occur and in general a somewhat improved directivity might be expected because of the ripple nature of the theoretical directivity. This is borne out by measured results (Fig. 5). An overall improvement of several db in directivity over the 20 db coupler is obtained.

**VSWR**

The input VSWR of a directional coupler used for measuring the value of small reflections is generally not of major importance. It is usually sufficient that a moderately good match exist between the signal source and the coupler. In the case of these multi-hole couplers, an unusually small VSWR of less than 1.05 for both the 10 and 20 db couplers resulted.

**CROSS-GUIDE COUPLER**

For many applications the precision of the *-hp-* multi-hole type couplers is not required. For these applications it is usually sufficient that the coupling be relatively constant over the range of a standard wave guide and that the directivity (in db) be not less than the coupling (in db).

An inexpensive and compact type of directional coupler suited to this type of application is the cross-guide coupler[1] shown in Fig. 6. This

[1]The basic design for the cross-guide coupler is due to T. Moreno.

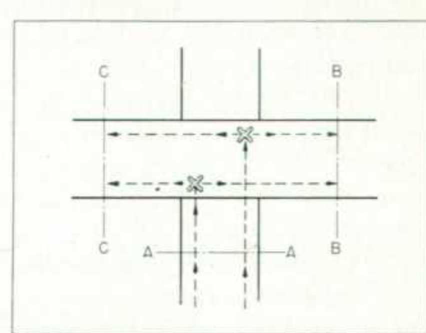


Fig. 6. *Basic arrangement of cross-guide type directional coupler.*

coupler consists of two wave guide sections joined at right angles across their broad faces.

The coupling apertures are designed in the form of slots so that the coupling will be related primarily to the magnetic fields. Crossed slots are used to achieve the desired coupling with minimum slot length.

The coupling apertures are located so that the path length from plane A to plane B (Fig. 6) for the wave coupled through one aperture is equal to the path length for the wave coupled through the second aperture. The two paths from plane A to plane C are not equal, however.

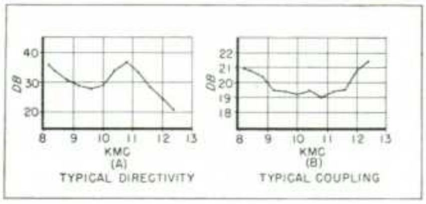


Fig. 7. *Characteristics of typical -hp- 20 db cross-guide coupler.*

It can be shown that the magnetic fields at one side of the guide will couple into the auxiliary guide through one aperture fields that are 180° out of phase with those coupled through the other aperture from the other side of the guide. Since the two path lengths from A to B are equal and since the coupling apertures are identical, complete cancellation will occur in the B direction. In the C direction, however, the path lengths are unequal and cancellation will not occur.

The apertures are located so as to obtain a reasonably constant coupling over the range of a wave guide. This location is such that the change in forward radiation with frequency caused by the relative phase variation between the two waves is balanced against the change in aperture coupling with frequency.

A 20 db and a 30 db design for cross-guide couplers have been established in the 8,200 to 12,400 megacycle range. Typical variation of coupling and directivity for the 20 db coupler over the wave guide frequency range are shown in Fig. 7.

No load is included in the cross-guide couplers. Since these couplers are useful in many types of applications such as mixing and isolation, the presence of a load would limit their versatility. —*E. F. Barnett* and *J. K. Hunton*

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The Ron Merritt Company of Seattle has recently been appointed -hp- sales engineering representative for the states of Washington and Oregon and for parts of Idaho and Montana.

Mr. Merritt has an extensive background in the electronics business and is widely acquainted among electronics people in the Northwest area. His business location is 217 Ninth Avenue North, Seattle, telephone Seneca 4948.

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