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# More About the *-hp-* Precision Directional Couplers

AN earlier issue[1] described the design of the *-hp-* 10 and 20 db precision multi-hole directional couplers. These couplers are distinguished by a relatively constant coupling over a wave guide range of frequencies and by an unusually high directivity of more than 40 db, even for coupling values as tight as 10 db.

The multi-hole coupler design has now been extended to a 3 db coupler, that is, a coupler in which half the power entering the main guide is coupled into the auxiliary guide. This coupler has the same constancy of coupling and high directivity as the 10 and 20 db values. In addition, specifications have been established for all couplers on the basis of production experience.

The *-hp-* multi-hole couplers consist of two sections of wave guide mutually coupled by two rows of coupling holes (Fig. 2). Power entering the input arm of the coupler flows down the main guide and divides at the coupling mechanism. Part of the power continues down the main guide where it will be incident on any device connected at the end of the guide. The other part of the power is coupled into the auxiliary guide. It is a property of directional couplers that the power coupled into the auxiliary guide flows essentially in only one direction. In the *-hp-* coupler, this power flow is in the same direction as the power in the primary guide.

In the ideal condition all of the power coupled to the auxiliary guide should flow in the same direction. Practically, however, a portion of the auxiliary guide power flows in the reverse direction. The ratio of auxiliary guide power flowing in the desired direction to that flowing in the reversed direction is termed the directivity of the coupler. In the past the use of directional couplers has been limited by lack of high directivity over a full wave guide frequency range. It is this feature of high directivity over a broad range that has received the attention of designers in recent years and it is in this feature that the *-hp-* multi-hole couplers are distinctive.

To a first order effect, the lengths of the rows of coupling holes shown in Fig. 2 are chosen to obtain very high directivity for the coupling mechanism itself. The voltage coefficients of coupling of the individual holes are separately chosen to obtain the desired coupling value and at the same time to obtain the desired type of reverse radiation spectrum. The reverse radiation is designed to

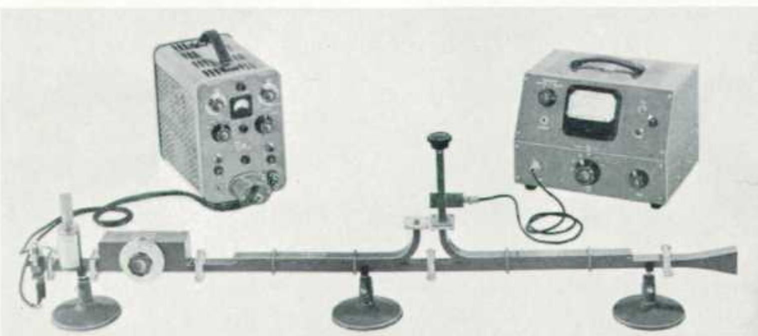

Fig. 1. *Two -hp- multi-hole directional couplers in a reflectometer arrangement for measuring reflection coefficient magnitude. In background are an -hp- 715A klystron power supply to power signal source and an -hp- 415A standing-wave indicator to read output of detector.*

[1]E. F. Barnett and J. K. Hunton, "A Precision Directional Coupler Using Multi-Hole Coupling," Hewlett-Packard Journal, Vol. 3, No. 7-8, March-April, 1952.

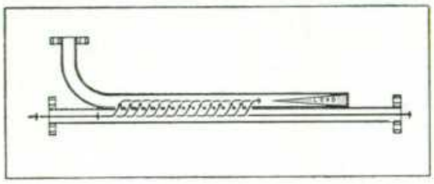

Fig. 2. *Cross-sectional drawing of -hp- multi-hole coupler.*

approximate zero over a wave guide spectrum in an equal-ripple (Tschebyscheff) manner. This type of approximation has the advantage over other possible approximations that the coupling mechanism itself has a directivity that is the maximum obtainable over the wave guide band with a given number of coupling elements.

### NEW 3 DB COUPLER

Since the 3 db coupler has the high directivity of the 10 and 20 db couplers, it can usually be used in place of hybrid Tees in measuring small reflections. In such applications the *-hp-* multi-hole directional coupler is as good as the best available hybrid Tees, because the directivity of the multi-hole coupler is as good as the isolation between the input arms of such Tees. Furthermore, the multi-hole coupler, unlike the hybrid Tee, is a matched device having a low VSWR of 1.05 or less over a wave guide frequency range.

Although the 3 db multi-hole coupler has the above advantages over hybrid Tees, it may nevertheless be desirable to consider other coupling values when measuring small reflections as described later.

### APPLICATION CONSIDERATIONS

In the past directional couplers have been used mainly for monitoring power levels and for mixing, but they also have important advantages when used in measuring small reflections. For one thing, the *-hp-* directional couplers are broad band devices which can be used over an entire wave guide frequency band without necessity for tuning. Even more important, however, is the fact that the use of directional couplers leads to the measurement of reflection coefficient rather than VSWR. When working with small reflections, it is easier to measure reflection coefficient accurately than it is VSWR. For small VSWR's, the measurement requires working with the ratio of two nearly equal values. If reflection coefficient is then calculated from these values, the result is likely to be inaccurate. Consequently, a direct measurement of reflection coefficient is to be preferred. The same reasoning will indicate that it is preferable to make a direct measurement of VSWR when working with large reflections.

The factor which makes the *-hp-* multi-hole couplers important in measuring small reflections is their high directivity of 40 db or more. This directivity is generally 10 db better than that formerly obtained over a wave guide band. A directivity of 40 db makes a system using these couplers about equal in accuracy to the best slotted line sections and at the same time offers the advantage of a direct measurement of reflection coefficient.

The couplers are designed as three-arm devices. At what would be the fourth arm there is included a built-in termination as indicated in the cross-sectional drawing of Fig. 2. When used in measuring the amplitude of small reflections, the couplers are designed to be connected so that the power coupled in the forward direction in the auxiliary guide is absorbed by the termination. This termination has been designed to have not more than 0.5% reflection, because such reflection reduces the overall directivity of the coupler. The 40 db directivity specified for the couplers includes the effect of termination reflections.

When used in monitoring power levels, the connections of the coupler should be reversed so that the power coupled into the auxiliary guide is available at the auxiliary terminal.

### REFLECTOMETER SET-UP

A typical reflectometer for measuring the magnitude of small reflection coefficients is illustrated in Fig. 3. A modulated signal source of thirty milliwatts or more output is connected to the directional coupler system, using an attenuator for isolation of the source. Two directional couplers are connected back-to-back as shown. The device to be measured is connected at the forward end of the second coupler.

At the two auxiliary arms A and B of the couplers, an *-hp-* Model 485 tuned detector mount is shown. This mount can be used with a type 821 barretter as the detector element and an *-hp-* Model 415A as the voltage indicator. The 415A gives a full-scale reading on detector outputs as low as 0.3 microvolt and has an upper limit of 0.3 volt so that it is nicely suited to the measurements. The 415A also includes a d-c source for biasing the barretter element.

Reflection coefficient is determined by measuring two quantities: the voltage incident on the device to be measured and the voltage reflected from the device. The incident voltage is measured by connecting the Model 485 detector mount to arm A and noting the reading obtained on the 415A. It is convenient that this reading be made exactly full scale on the 415A. The 415A includes a gain adjustment to simplify this procedure.

After making the initial adjustment, the detector mount can be moved to arm B to measure the reflection coefficient. Using two 10 db couplers as indicated in Fig. 3, the reflection coefficient will be given directly in db below the initial reading on the 415A. This direct reading feature occurs because the levels measured at A and B have each been attenuated 10 db owing to coupler action.

The reflectometer using two 10 db couplers involves an error in the value of the reflection coefficient of approximately 0.9 db because of the power split off by each coupler, but this error is constant and can thus be readily corrected.

Other possible arrangements of the equipment can be used to measure reflection coefficient. For ex-

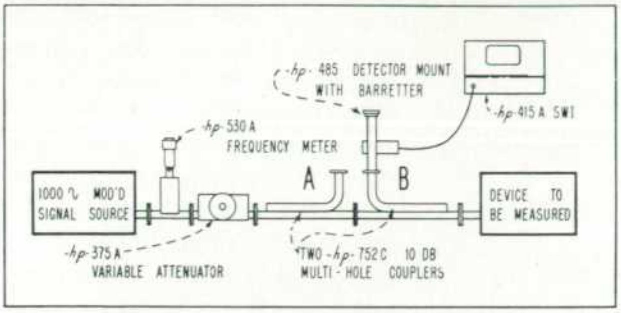


Fig. 3. *Equipment arrangement for measuring reflection coefficient.*

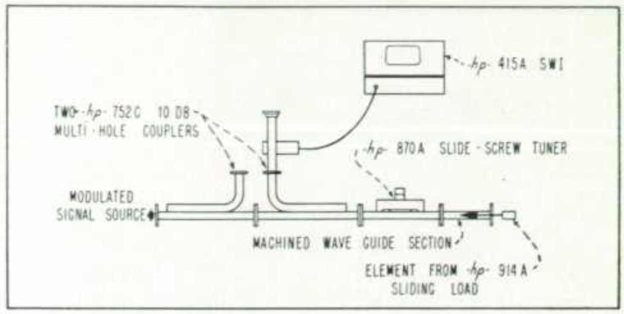


Fig. 4. *Equipment arrangement for obtaining a system having maximum directivity.*

ample, a single directional coupler can be used instead of a pair. This arrangement, however, has the disadvantage that the load must be disconnected each time a measurement of forward power is desired, and forward power should be measured each time frequency is changed.

Other values of couplers can also be used, but the two 10 db couplers offer a nice compromise between convenience and sensitivity. Maximum sensitivity will be obtained in the measurements by using a single 3 db coupler. The gain in sensitivity over a pair of 10 db couplers is 4.9 db.

#### JUNCTION REFLECTIONS

To measure reflection coefficient accurately, it is necessary that undesired reflections in the system beyond the coupling mechanism be kept small compared to the reflection to be measured. In practical applications, the joint at the forward end of the main guide will often be a source of such undesired reflections. To minimize joint reflections, it is necessary that the joint present negligible discontinuity. In wave guide, joint discontinuity occurs from several causes. First, the two joined sections may differ in size because of tolerances existing in wave guide. Second, the guide may be distorted as a result of flange soldering. Third, the flange surfaces may be such as to prevent an electrically continuous joint. Fourth, the wave guide sections may be physically misaligned.

The *-hp-* multi-hole couplers are fabricated from selected metal stock whose dimensions are checked carefully. In testing at the factory, the couplers are joined to a piece of machined wave guide whose dimensions are accurate within 0.1%. This gives a standard test section against which to compare the performance of the coupler. The directivity of 40 db specified for the couplers includes the effect of any reflections that occur when the couplers are connected to this test section.

In practice, reflections from the joint at the forward end of the coupler can be minimized by insuring that the dimensions of the guide section to be attached to the coupler are accurate. Further, the guide section should be free from warpage, while the joined section should be carefully aligned so that offsetting does not occur.

If these precautions are followed, joint reflections can be held to less than 0.2%.

#### HIGHER DIRECTIVITY

The overall directivity of the multi-hole coupler is influenced by two sources of reflection within the coupler itself. First, some reflection occurs from the built-in termination in the auxiliary guide. Second, the imperfection of the coupling mechanism itself results in transmission of a small wave to the reverse terminal of the auxiliary guide. Reducing either of these components will improve the directivity of the coupler.

Following the precautions regarding reflections at joined sections will aid in obtaining a system that is approximately equal in quality to the best slotted line systems. Where the utmost in directivity is desired, however, and where the application justifies extra effort, the directivity of the coupler can, in effect, be improved by external means so that even smaller reflections can be measured.

A set-up is indicated in Fig. 4 for obtaining maximum directivity with the multi-hole couplers. In this set-up a slide-screw tuner is located immediately following the coupler. Theoretically, the tuner can be adjusted to set up a reflection that will be equal in amplitude and opposite in phase to the resultant of the undesired reflections received at the reverse auxiliary terminal of the coupler. The tuner reflection will thus cancel the other reflections and perfect directivity will be obtained. In practice, careful adjustment of the tuner will result in an effective directivity of 70 db or more.

In order to obtain this high directivity, it is necessary that the tuner be adjusted while the system is terminated with a very flat, movable load. Such a load has been described in an earlier issue.[2] The device consists of a load with small reflection coefficient mounted in a wave guide section and provided with a handle to permit the load to be moved within the section. The load permits its own small reflection to be distinguished from other reflections in the system, because the relative phases of the reflections are changed when the load is moved.

To adjust the set-up of Fig. 4 for maximum directivity, the slide-screw tuner should be adjusted until

[2]J. K. Hunton and W. B. Wholey, "The 'Perfect Load' and the Null Shift," Hewlett-Packard Journal, Vol. 3, No. 5-6, Jan.-Feb., 1952.

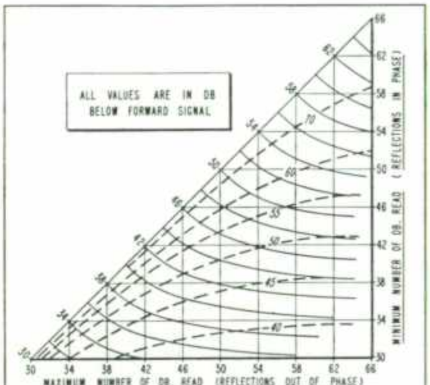


Fig. 5. *Chart for determining level of each of two reflections in db below incident power.*

a condition is achieved where moving the sliding load causes no variation in the reading of the 415A. In the usual case, the mean reading on the 415A will decrease as the tuner is adjusted, but the amplitude of the variation in the reading when the load is moved will first increase. This variation will reach a maximum when the two reflections are equal in magnitude. As the tuner is further adjusted and the directivity reflection becomes more fully cancelled, the amplitude of the variation will decrease. The end point occurs when the variation becomes very small, usually one db or less on the meter scale.

The value of each reflection can be determined from the chart shown in Fig. 5. To use this chart, it is only necessary to measure the maximum and minimum value of the variation in db below the level of the input power to the coupler. For example, assume that these readings are −48 and −50 db. Referring to Fig. 5, it will be seen that one reflection has a value of −49 db and the other a value of −69 db. Since the directivity reflection has been adjusted to be less than the load reflection, it is the smaller of the two reflections and has a value of 69 db below the coupler input power.

By adjusting the tuner, the directivity of the system can be made arbitrarily high at any one frequency. One of the advantages of the foregoing system is that the directivity can be adjusted to be below the noise level of the equipment if desired. The reason for this is that the directivity reflection adds to the sliding load reflection and can be measured by the above procedure, even though it is too small to be measured by itself.

When highest directivity is desired, the foregoing adjustments should be made with the sliding load element removed from its regular housing and placed in a wave guide section having flanges on both ends. Once the system is adjusted, then, it will not be disturbed by removing the sliding load element and connecting the device to be measured to the end of the special housing.

Fig. 6. *-hp- Model 750 cross-guide type directional coupler.*

**CROSS GUIDE COUPLERS**

The *-hp-* series of directional couplers also includes a group of cross-guide type coupler in 20 and 30 db coupling values. These couplers are useful in many applications such as mixing where the precision of the multi-hole coupler is not required. The cross-guide couplers are four-terminal devices which do not include a built-in load. Performance data for the cross-guide couplers are given in the specifications which follow.

*—E. F. Barnett*



**SPECIFICATIONS**
**-hp-**
**MODEL 752**
**MULTI-HOLE COUPLERS**

*DIRECTIVITY:* Better than 40 db over entire range.
*COUPLING ACCURACY:* Mean coupling level is within 0.4 db of specified value.
*COUPLING VARIATION:* Not more than ±0.5 db over frequency range.

| Model | Coupling | Frequency Range (kmc) | Wave Guide Size (in.) | Approx. Length (in.) | Price |
|---|---|---|---|---|---|
| S752C | 10 db | 2.6 -3.95 | 3x1½ | 39 | $210.00 |
| S752D | 20 db | 2.6 -3.95 | 3x1½ | 39 | 210.00 |
| G752A | 3 db | 3.95-5.85 | 2x1 | 30 | 170.00 |
| G752C | 10 db | 3.95-5.85 | 2x1 | 30 | 170.00 |
| G752D | 20 db | 3.95-5.85 | 2x1 | 30 | 170.00 |
| J752A | 3 db | 5.85-8.20 | 1½x¾ | 24 | 140.00 |
| J752C | 10 db | 5.85-8.20 | 1½x¾ | 24 | 140.00 |
| J752D | 20 db | 5.85-8.20 | 1½x¾ | 24 | 140.00 |
| H752A | 3 db | 7.05-10.0 | 1¼x⅝ | 18½ | 120.00 |
| H752C | 10 db | 7.05-10.0 | 1¼x⅝ | 18½ | 120.00 |
| H752D | 20 db | 7.05-10.0 | 1¼x⅝ | 18½ | 120.00 |
| X752A | 3 db | 8.2 -12.4 | 1x½ | 15½ | 100.00 |
| X752C | 10 db | 8.2 -12.4 | 1x½ | 15½ | 100.00 |
| X752D | 20 db | 8.2 -12.4 | 1x½ | 15½ | 100.00 |

*DELIVERY NOTE:* Delivery of the 3 db coupler for the 8.2-12.4 kmc range (Model X752A) is approximately 90 days; delivery of 3 db coupler for other ranges is somewhat longer.

**SPECIFICATIONS**
**-hp-**
**MODEL 750**
**DIRECTIONAL COUPLERS**

*DIRECTIVITY:* Approx. 20 db or more.
*COUPLING ACCURACY:* Mean coupling level is within 0.4 db of specified value.
*COUPLING VARIATION:* Within ±1.3 db over frequency range.

| Model | Coupling | Frequency Range (kmc) | Wave Guide Size (in.) | Physical Size (in.) | Price |
|---|---|---|---|---|---|
| S750D | 20 db | 2.6 -3.95 | 3x1½ | 9x9 | $100.00 |
| S750E | 30 db | 2.6 -3.95 | 3x1½ | 9x9 | 100.00 |
| G750D | 20 db | 3.95-5.85 | 2x1 | 6x6 | 85.00 |
| G750E | 30 db | 3.95-5.85 | 2x1 | 6x6 | 85.00 |
| J750D | 20 db | 5.85-8.20 | 1½x¾ | 5x5 | 70.00 |
| J750E | 30 db | 5.85-8.20 | 1½x¾ | 5x5 | 70.00 |
| H750D | 20 db | 7.05-10.0 | 1¼x⅝ | 4x4 | 60.00 |
| H750E | 30 db | 7.05-10.0 | 1¼x⅝ | 4x4 | 60.00 |
| X750D | 20 db | 8.2 -12.4 | 1x½ | 3x3 | 50.00 |
| X750E | 30 db | 8.2 -12.4 | 1x½ | 3x3 | 50.00 |

Prices f.o.b. Palo Alto, California
Data subject to change without notice