New Coaxial Couplers for Reflectometers, Detection, and Monitoring

Coaxial couplers with flattened response and high directivity facilitate swept-type measurements of several kinds.

Accurate reflectometer measurements in coaxial systems were made practical by the development of suitable directional couplers at Hewlett-Packard ten years ago. Not only were these couplers useful in reflectometer applications because of their octave frequency response and high directivity, but their accurate coupling and low SWR made them attractive for other applications as well, such as for accurate attenuation or as take-offs for frequency and power monitoring.

Three new series of coaxial couplers, all with better directivity and flatter frequency response, have now been developed at -hp- to meet the needs of a variety of applications, including reflectometers, power and frequency monitoring, and detection. One type is a high-directivity coupler with a frequency response that is constant within ±0.3 db over an octave band of frequencies. The second type, more appropriately known as a directional detector, is a combination

SEE ALSO:
Waveguide detectors with flat response, p. 6.
New time unit for WWV8, p. 8.

Fig. 1. Flat frequency response of new -hp- Directional Couplers and Detectors is especially advantageous in closed-loop power-leveling systems, such as in the swept-frequency evaluation of coaxial filter frequency response being made here by -hp- design engineers Larry Renihan (left) and Auber Ryals. Directional Detector, which supplies error signal for automatic leveling loop, senses RF power right at point of measurement.

of the new directional coupler and a diode detector element that is mounted directly on the coupler arm, as shown in Fig. 7. The combination of detector and coupler in one package improves accuracy in closed-loop power leveling set-ups by eliminating the ambiguities that exist when a connector intervenes between detector and coupler.

The third new coupler is a dual directional coupler, combining two directional couplers back-to-back in a single package for reflectometer applications. This arrangement is one that also eliminates some connector mismatches by combining the couplers in one package. In addition, the dual directional couplers have high directivity,* 40 db in those units which cover the 215 to 1900 Mc portion of the spectrum and 30 db in those that are for 1900 to 4000 Mc. The high directivity reduces SWR errors to very low levels in reflectometer measurements.

**DIRECTIONAL COUPLER**

The new directional couplers (Fig. 2) are useful for monitoring microwave power, particularly in power-leveling applications where it may be desired to use either a thermistor or barretter connected to the auxiliary arm.

When monitoring power in swept-frequency applications, the most significant source of errors is usually the frequency response of the coupler. Although the finite directivity of the coupler may contribute other errors, these assume negligible proportions for moderate standing-wave ratios if the directivity of the coupler is high.

Errors are thus reduced by the very flat frequency response of the new -hp- Directional Couplers. The coupler design holds frequency response variations to less than ±0.3 db over more than an octave band by division of the coupling arm into two coupling elements in series. The elements have different coupling values so that the power coupling curve has the form:

$$k_1 \sin^2 \beta_1 + k_2 \sin^2 \left(2\beta_1\right),$$

where $\beta_1$ pertains to the electrical length of the elements. By manipulation of $k_1$ and $k_2$, related to the coupling of the individual elements, the coupling curve has been shaped into an equal ripple function in the desired band, as shown in Fig. 3. This curve, incidentally, represents the output coupling (ratio of output power to power in the auxiliary arm) rather than the more commonly specified coupling factor (ratio of input power to power in the auxiliary arm). Output coupling relates the power sensed at the auxiliary output directly to the actual power delivered to the system, as defined in Fig. 4.

The new directional couplers are especially useful as take-offs for power or frequency monitoring in RF systems. They can tolerate input powers up to 50 w CW. Fig. 5 shows one application in which the coupler serves a double purpose as a power monitor take-off and as a 20-db attenuator for sensitivity meas-
urements. The couplers can function either with crystal detectors or with power measuring equipment, such as the -hp- Model 478A Coaxial Thermistor Mount and Model 431B Power Meter.

**DIRECTIONAL DETECTOR**

The new Directional Detectors are directional couplers with diode detectors installed directly on the coupler arms (Fig. 7). Not only does this arrangement remove the ambiguities that arise when there is a connector between coupler and detector, but it also allows the two elements to be tested and specified as a unit.

The detector element in the Directional Detectors is the same semiconductor diode assembly developed for the exceptionally flat -hp- Model 423A Crystal Detectors.2,3 As shown in Fig. 6, the combination of coupler and broadband detector in one unit achieves very good frequency response.

Three of the Directional Detectors use the same coaxial configuration as the new Directional Couplers. The X-band Directional Detectors, however, are hybrid devices that use a double-stacked compensated waveguide coupler to obtain flat coupler response throughout X-band (Fig. 12). One of the X-band detectors is for use in coaxial systems and has transition sections that match the waveguide sections to coaxial connectors at both ends. The other one has a coaxial input but uses a waveguide cover flange for the output connector. This configuration is useful when a monitor is required for a waveguide system driven by a signal source with coaxial output.

**POWER LEVELING**

A Directional Detector can serve as a power take-off for leveling the output of a sweep oscillator, as illustrated by the application shown in Fig. 8. This use of a detector external to the sweep oscillator makes it possible to maintain constant power at some selected point in the external system, regardless of the characteristics of cables, connectors, or other devices between the RF source and the Directional Detector.

If the device at the output of the coupler is poorly matched, the flatness of leveling is influenced by the coupler directivity. For instance, a terminating impedance that has an SWR of 1.5 has 14 db return loss (ratio of incident to reflected power) and this is added to the directivity of the Directional Detector to obtain the ratio of forward to reflected power in the auxiliary arm.

Fig. 5. Receiver sensitivity measurements uses -hp- Model 796D Directional Coupler to attenuate RF power 20 db below level indicated by power meter connected to main output.

Fig. 6. Frequency response of typical 787D Directional Detector.

Fig. 7. Model 786D Directional Detector and equivalent schematic. Diode detector is in sealed capsule easily replaced without special tools.

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3 Lawrence Renihan and Robert Pickett, "New Waveguide Crystal Detectors with Flat Response," Hewlett-Packard Journal, this issue.
auxiliary arm. This results in an error of only 0.62% in the voltage at the load. Thus, high directivity in a coupler or directional detector is important for measurement accuracy.

REFLECTOMETERS

A coaxial reflectometer system using one of the new Dual Directional Couplers is shown in Fig. 9. In reflectometer systems, the source of the most significant errors is the finite directivity of the couplers, rather than the frequency response. Since both forward and reverse arms of the new Dual Directional Couplers have identical coupling variations with respect to frequency, the variations are self-canceling and do not affect the VSWR reading. The frequency response of the forward coupler, which is in the automatic leveling loop, causes the power vs. frequency characteristic of the main line to be "pre-emphasized," thus compensating for the frequency response of the reverse coupler.

The directivity required to prevent addition of significant amounts of forward power to the reflected signals in the reverse coupler, for various values of SWR, is shown in Table I. The directivity of the new Models 774D through 776D is 40

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**SPECIFICATIONS**

**MODELS 796D, 797D, 798C DIRECTIONAL COUPLERS**

<table>
<thead>
<tr>
<th>FREQUENCY RANGE:</th>
<th>0.95</th>
<th>1.9</th>
<th>3.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>211 Mc</td>
<td>4.1 Gc</td>
<td>8.3 Gc</td>
<td></td>
</tr>
<tr>
<td>MEAN OUTPUT COUPLING:</td>
<td>±0.5 db</td>
<td>±0.5 db</td>
<td>±0.3 db</td>
</tr>
<tr>
<td>OUTPUT COUPLING VARIATION:</td>
<td>±0.2 db</td>
<td>±0.2 db</td>
<td>±0.3 db</td>
</tr>
<tr>
<td>DIRECTION:</td>
<td>30 db</td>
<td>26 db</td>
<td>20 db</td>
</tr>
<tr>
<td>MAX. PRIMARY LINE SWR:</td>
<td>1.15</td>
<td>1.15</td>
<td>1.20</td>
</tr>
<tr>
<td>MAX. SECONDARY LINE SWR:</td>
<td>1.20</td>
<td>1.25</td>
<td>1.20</td>
</tr>
<tr>
<td>PRIMARY LINE INSERTION LOSS:</td>
<td>0.25 db</td>
<td>0.35 db</td>
<td>0.6 db</td>
</tr>
<tr>
<td>EQUIVALENT SOURCE MATCH:</td>
<td>1.13</td>
<td>1.16</td>
<td>1.25</td>
</tr>
<tr>
<td>PRICE:</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$225.00</td>
</tr>
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</table>

**MODELS 774D, 775D, 776D, 777D DUAL DIRECTIONAL COUPLERS**

<table>
<thead>
<tr>
<th>FREQUENCY RANGE:</th>
<th>215</th>
<th>450</th>
<th>940</th>
<th>1.9</th>
<th>4.0</th>
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<tbody>
<tr>
<td>450 Mc</td>
<td>940 Mc</td>
<td>1.9 Gc</td>
<td>4.0 Gc</td>
<td></td>
<td></td>
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<tr>
<td>MINIMUM DIRECTIVITY:</td>
<td>40 db</td>
<td>40 db</td>
<td>40 db</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. COUPLING VARIATION:</td>
<td>±1 db</td>
<td>±1 db</td>
<td>±0.4 db</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUXILIARY ARM TRACKING:</td>
<td>≤0.3 db</td>
<td>≤0.3 db</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. PRIMARY LINE SWR:</td>
<td>1.15</td>
<td>1.2</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. AUXILIARY ARM SWR:</td>
<td>1.20</td>
<td>1.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRIMARY LINE INSERTION LOSS:</td>
<td>0.15 db</td>
<td>0.20 db</td>
<td>0.25 db</td>
<td>0.6 db</td>
<td></td>
</tr>
<tr>
<td>PRICE:</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$200.00</td>
<td>$250.00</td>
<td></td>
</tr>
</tbody>
</table>

**ALL UNITS:** Coupling Attenuation (each secondary arm): 20 db.

**ACCURACY OF COUPLING** (each secondary arm): Mean coupling level within 0.5 db of specified values.

**POWER HANDLING CAPACITY:** 50 watts ave., 10 kw peak.

**PRIMARV LINE CONNECTORS:** Precision Type N connector, one male and one female.

**AUXILIARY ARM CONNECTORS:** Precision Type N female connectors.

**ACCESSORIES AVAILABLE:** -hp- 11511A Type N Female Shorting Jack, $4.00. -hp- 11512A Type N Male Shorting Plug, $4.50 (for reflectometer calibration).

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Prices f.o.b. factory.

Data subject to change without notice.

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db, a directivity that results in SWR ambiguities of only 1.02 and that provides an accuracy in reflectometer applications approaching that obtained with time-consuming, point-by-point slotted line measurements. Directivity of the higher frequency Model 777D is 30 db, resulting in SWR ambiguities of less than 1.06.

The two couplers in the Dual Directional Couplers (Fig. 10) are made up of single elements for highest possible directivity and for reduction of transition discontinuities to a minimum. The coupling curve of a single element is of the form $k \sin \beta l$, so that the coupling varies about 1.3 db across an octave band. The coupling variations of both arms of the new dual directional coupler, of course, are self-canceling in reflectometer applications.

**MECHANICAL CONSIDERATIONS**

All three types of couplers are housed in rigid, cast aluminum bodies (except for the hybrid waveguide types). The precision type N connectors are of stainless steel for maximum wear resistance in applications requiring frequent connect-disconnect cycles.

(Continued on Page 8)
NEW WAVEGUIDE CRYSTAL DETECTORS
WITH FLAT RESPONSE

Until recently, accuracy in fast, repetitive microwave swept frequency measurements was limited by the frequency response of available crystal detectors. Frequency response variations of ±2 dB across a waveguide band of frequencies were typical of the best crystal detectors formerly available.

Now, a new series of waveguide crystal detectors provides a frequency response that is better than ±0.2 dB up to 10 Gc and ±0.5 dB up to 18 Gc. High accuracy is now possible in fast, swept-frequency measurements that use oscilloscope display, allowing transmission-loss and SWR to be read directly from the oscilloscope graticule.* With such measurement set-ups, results not only are accurate but they also are fast, enabling on-the-spot evaluation of component adjustments.

Frequency response variations in the new crystal detectors, the -hp-424 Series, are less than ±0.2 dB across each waveguide band up to 10 Gc. Across X band (8.2–12.4 Gc), the frequency response variations are less than ±0.5 dB and across M and P band (10–18 Gc), less than ±0.5 dB. In addition, the response of any two of the new detectors is so nearly identical that selection for matched pairs ordinarily is not necessary, although matched pairs can be selected for the most exacting applications.

The flat frequency response is also advantageous in peak and relative power measurements and for systems using closed-loop power leveling. Furthermore, the new detectors have improved square law characteristics which, along with the flat frequency response, assures accurate measurements throughout the band in reflectometer applications.

*Swept Frequency Measurements

Frequency response as flat as that achieved by the new crystal detectors means that other sources of error in measurement set-ups assume increased importance. The dominant source of errors now becomes the inevitable frequency response of the waveguide couplers, and this can be compensated for by appropriate arrangement of the couplers. One such arrangement is shown in Fig. 1. Here, the frequency response of the 3-db coupler's main arm is the inverse of the auxiliary arm, as shown by curves “c” and...
Fig. 4. Series of seven detectors matches waveguide sizes from S through P bands. Diode elements are in sealed capsules, easily replaced without special tools or soldering.

"d" of Fig. 3. The 3-db coupler thus compensates for the frequency response of the 10-db coupler and power variations are thereby held to within a few tenths of a db across the band.

Mismatch errors are minimized by use of the new detector with high-quality couplers. An \(-hp-\) 752C Coupler with a 424A Detector presents a SWR of only 1.05 to the main guide.

**DIODE DETECTORS**

The flat response of the new waveguide detectors is achieved primarily through use of an \(-hp-\) developed diode, the same one used in the new Coaxial Crystal Detectors. The diode presents a broadband impedance match to a coaxial line by means of a 50-ohm resistive film on the outside surface of the diode cartridge. The point-contact rectifying junction is thus physically close to the terminating resistor and it appears to the coaxial line as a high impedance shunting the resistor. A transition section matches the coaxial section to waveguide; the resulting SWR is less than 1.35 in S through X bands, and less than 1.5 in M and P bands.

Low output resistance and low capacitance combine to give the detectors good pulse characteristics. The detectors therefore are useful (Continued on Page 8)

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**SPECIFICATIONS**

\(-hp-\) MODEL 424A WAVEGUIDE CRYSTAL DETECTORS

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequency (Gc)</th>
<th>Freq. Resp.* (db)</th>
<th>Low Level (mv dc /w cw)</th>
<th>High Level (mw)</th>
<th>Max. SWR</th>
<th>Fits Waveguide Nom. OD (in.)</th>
<th>Size (EIA)</th>
<th>Equivalent Flange</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>S424A</td>
<td>2.6 - 3.95</td>
<td>±0.2</td>
<td>&gt;0.4</td>
<td>1.35</td>
<td>3 x 1/2</td>
<td>WR 284</td>
<td>UG-53/U</td>
<td>UG-419/U</td>
<td>175.00</td>
</tr>
<tr>
<td>G424A</td>
<td>3.95 - 5.85</td>
<td>±0.2</td>
<td>&gt;0.4</td>
<td>1.35</td>
<td>2 x 1</td>
<td>WR 187</td>
<td>UG-149A/U</td>
<td>165.00</td>
<td></td>
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<tr>
<td>J424A</td>
<td>5.3 - 8.2</td>
<td>±0.2</td>
<td>&gt;0.4</td>
<td>1.35</td>
<td>1 ½ x 3/4</td>
<td>WR 137</td>
<td>UG-344/U</td>
<td>165.00</td>
<td></td>
</tr>
<tr>
<td>H424A</td>
<td>7.05 - 10.0</td>
<td>±0.2</td>
<td>&gt;0.4</td>
<td>1.35</td>
<td>1 ¼ x 5/8</td>
<td>WR 112</td>
<td>UG-51/U</td>
<td>155.00</td>
<td></td>
</tr>
<tr>
<td>X424A</td>
<td>8.0 - 12.4</td>
<td>±0.3</td>
<td>&gt;0.4</td>
<td>1.35</td>
<td>1 x ½</td>
<td>WR 90</td>
<td>UG-39/U</td>
<td>135.00</td>
<td></td>
</tr>
<tr>
<td>M424A</td>
<td>10.0 - 15.0</td>
<td>±0.5</td>
<td>&gt;0.3</td>
<td>1.5</td>
<td>0.850 x 0.475</td>
<td>WR 76</td>
<td>Cover Flange</td>
<td>250.00</td>
<td></td>
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<tr>
<td>P424A</td>
<td>12.4 - 18.0</td>
<td>±0.5</td>
<td>&gt;0.3</td>
<td>1.5</td>
<td>0.702 x 0.391</td>
<td>WR 62</td>
<td>UG-419/U</td>
<td>175.00</td>
<td></td>
</tr>
</tbody>
</table>

**FOR ALL MODELS:**

**OUTPUT IMPEDANCE:** 15k max., shunted by approximately 10 pf.

**DETECTOR ELEMENT:** Supplied.

**MAXIMUM INPUT:** 100 mw, peak or average.

**NOISE:** <200 µV pk-pk, with cw power applied to produce 100 mw output.

**OUTPUT POLARITY:** Negative.

**OUTPUT CONNECTOR:** BNC female.

**Options:**

01. Matched pair. Frequency response characteristics (exclusive of basic sensitivity) track within ±0.2 db for S, G, J, and H-band units, ±0.3 db for X-band units, and ±0.5 db for M and P-band units. Add $20.00 per unit.

02. Furnished with matched load resistor for optimum square law characteristics at 24°C (75°F). < ±0.5 db variation from square law from low level up to 50 mv peak output working into external load > 75k. Sensitivity typically > 0.1 mv/mw when load resistor is used. Add $20.00.

03. Positive polarity output. No additional charge.

Prices f.o.b. factory.

Data subject to change without notice.

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Fig. 5. Optional load resistor is matched to individual detectors for square law conformance within ±0.5 db from low level up to 50 mv peak output (at 24°C). Sensitivity of detector with load resistor is typically 0.1 mv/mw.
NEW COAXIAL COUPLERS

(Continued from Page 5)

Fig. 12. Directional Detectors for X-band consist of three waveguide sections with coupling holes between both interfaces. Coupling to bottom section "drains" enough energy to flatten frequency response of directional coupler formed by top and center sections.

ACKNOWLEDGMENTS

Much of the development work on the Directional Coupler and Directional Detectors was performed by Auber Ryals and Lawrence Renihan. Also, Richard Harmon contributed to the development of the Dual Directional Couplers.

—Robert Prickett

WAVEGUIDE DETECTORS

(Continued from Page 7)

for peak power measurements on short RF pulses, using a sensitive oscilloscope to read the detector output.

Detector sensitivity is greater than 0.4 mv dc per microwatt of CW input power (0.3 mv/µW in M and P bands), a three times improvement over previous waveguide crystal detectors. Uniform square-law response is maintained up to an input power level of —20 dbm (5 mv out). With some sacrifice in sensitivity, square-law response can be obtained over a much wider dynamic range, up to 50 mv peak output, by use of an optional matched video load (Fig. 5).

These new detectors represent an advance in the state of the art of broadband instrumentation and bring new simplicity and accuracy to many microwave measurements.

—Robert Prickett and Lawrence Renihan

Bob Prickett joined —hp— in 1957 as an R and D Engineer and since that time has been concerned with the design of a number of —hp—waveguide components, including the 422 K- and R-band Crystal Detectors, the 487 Thermistor Mounts, the 362 Filters, the 752 Couplers, and the 938A and 940A Frequency Doubblers. He has been Project Supervisor for the new waveguide Detectors and the new Coaxial Couplers and Directional Detectors.

Bob holds a BE degree from Vanderbilt University and both an EE and MS degree from MIT. He is a member of the IEEE and currently is chairman of the San Francisco chapter of the IEEE Group on Microwave Theory and Techniques.

Larry Renihan, a graduate of the California State Polytechnic College with a BS degree, joined —hp— in 1950. While at —hp—, Larry has been responsible for the design of the K- and R-band Waveguide Probe Carriage (Model 814B), Slotted Line Sections (815 Series), and Slide Screw Tuners (870 Series); also the X930 Waveguide Shorting Switch, the 906A Sliding Coaxial Termination, and the new 424 Series Waveguide Crystal Detectors. He also contributed to the design of the cavities in the Models 626A and 628A SHF Signal Generators.

ATOMIC TIME ADOPTED FOR WWVB

The National Bureau of Standards has announced that the new international unit of time is now being broadcast by NBS Low Frequency Standard Broadcast Station, WWVB. The new time unit, the atomic second, was adopted by the 12th General Conference on Weights and Measures in October 1964 and temporarily defined as the time interval spanned by 9 192 631 770 cycles of the transition frequency between two hyperfine levels of the atom of Cesium 133 undisturbed by external fields. This standard replaces the ephemeris second, adopted in 1956, which was defined as 1/31 556 925.9747 of the time taken by the Earth to orbit the sun during the tropical year 1900.

The new time unit is broadcast on WWVB as once-per-second amplitude-modulated time pulses repeated every 60 kc of the carrier. Accordingly, the WWVB 60-kc/s carrier is now maintained without offset and within a tolerance of ±2 x 10⁻¹¹ with respect to the U. S. Frequency Standard, a cesium-beam resonator.

Although WWVB no longer has the 150 parts in 10⁹ frequency offset that it had during 1964, NBS plans to periodically adjust the WWVB 1-second time pulses so that they are within approximately 0.1 second of UT2, a time scale based on the earth's rotation.

NBS stations WWV, WWVH, and WWVL will continue to be offset —150 x 10⁻¹⁰ from the U. S. Frequency Standard during 1965, as they were in 1964, and are thus in close agreement with UT2.

TIME PHASE ADJUSTMENTS

The master clocks at the NBS station were retarded 100 milliseconds (200 milliseconds at WWVB) on 1 Jan 65 because of changes in the speed of the earth's rotation. This adjustment is in accord with an international agreement that synchronizes within 1 millisecond the times of emissions of UT signals from the U. S. and other countries.