Recent Advances in Waveguide Hybrid Junctions*

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Summary—**Design techniques for waveguide hybrid tee junctions, resulting in convenient structures and simple internal matching elements for increased bandwidth and power-handling capacity are described, and experimental data are given.**

THE EVER-INCREASING variety of circuit applications of the waveguide hybrid junction has been the incentive for many advances in its design. Those which will be described are designs for a 12 per cent frequency band, featuring simple impedance-matching elements, high power-handling capability, or particularly convenient structures for connection to adjacent circuit elements.

To review briefly, a hybrid junction is basically a 4-port network, as shown in Fig. 1, so constructed that power incident at one port divides equally into two of the other ports, and does not pass directly to the fourth, or conjugate, port. The inverse relationship of two equal inputs producing full output from one port and zero from another also will be obtained, and is in fact a special case of the property that two coherent inputs produce their vector sum and difference at the other two ports. One other property of a hybrid junction is of interest: it is the only branching junction capable of appearing matched looking into any port when the other ports are terminated in their characteristic impedances. Typical waveguide forms of hybrid junctions shown in Fig. 2 are the *E-H* tee, (also called "magic" tee), the hybrid ring ("rat-race") and the 3 db directional-coupler ("short-slot") hybrid.

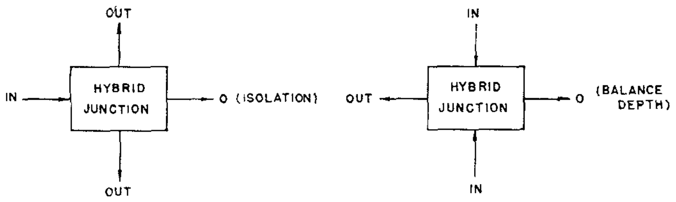

Fig. 1—Hybrid junction circuits.

Early applications of hybrid junctions in waveguide circuits were in balanced mixers, where two independent input signals are each divided equally between the two crystals; in impedance bridges, where two reflections are compared by observing their difference, and in power dividers, where equal power division is secured regardless of the load impedances. Later, hybrids found application in tuners, phase adjusters, balanced duplexers, and discriminator circuits. The most recent applications include the new type of "monopulse" radar described by Mr. Page of the Naval Research Laboratory at the 1955 IRE Convention, which uses the sum and difference signals from a hybrid for simultaneous determination of target range and angle; and the ferrite "circulator," a new nonreciprocal circuit element.

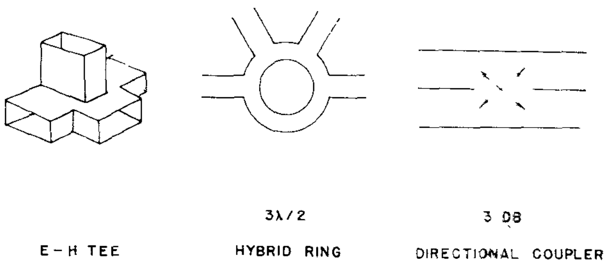

Fig. 2—Forms of waveguide hybrid junctions.

The wartime developments in hybrid junction design concerned principally tee and ring-type junctions. Many structures and matching elements for these junctions are described in detail in the M.I.T. Radiation Laboratory Series, principally volumes 8, 11, and 14, and in a comprehensive article by Tyrell.[1] Since then, Mr. Budenbom of the Bell Laboratories has presented extensive treatments of the hybrid ring junction. Mr. Riblet of the Microwave Development Laboratories has developed the directional-coupler type of hybrid to a high degree. His "short-slot" hybrids have excellent impedance match, good power capacity, and may be obtained quite inexpensively in many compact forms with various adapters. Mr. Sensiper and others at Sperry have achieved and patented a design for a hybrid tee junction with low reflection over the full 40 per cent waveguide bandwidth. This design, consisting of a wedge and pin within the junction and a small inductive iris in the *E* arm, has been adapted (with tapers where necessary) to all standard waveguide sizes, and is being defined by the Signal Corps as a military standard component.

Some of the most important needs in present applications of the waveguide hybrid junction are for easily specifiable internal dimensions, high power-handling

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[1] W. A. Tyrrell, "Hybrid circuits for microwaves," Proc. IRE, vol. 35, pp. 1294–1306; November, 1947.

capacity, convenient configurations for direct connection to adjacent circuit elements, and high isolation in both pairs of arms over a wide (12 per cent) frequency band. All of these needs have been met in varying degrees in the hybrids which will be described, which were developed by the Wheeler Laboratories for the Bell Telephone Laboratories. These are all centralized junctions, having two perpendicular, cross-polarized arms located in the plane of symmetry of the junction. An advantage of this type of structure is the inherent isolation of the perpendicular arms at all frequencies. If these two arms are also impedance-matched, the design of the junction is completed, for, by reciprocity, the collinear arms acquire the same properties of isolation and match.

For the conventional *E-H* tee structure, a new wideband matching element has been found for the *E* arm; this is a large cone located in the junction space, replacing the narrow-band inductive iris used in early tee designs. The cone, shown in Fig. 3, acts as a power-divider in the *E* arm, a cutoff-corner 90° *E*-plane bend, and a quarter-wavelength transformer from half to full height waveguide. Its location along the plane of symmetry of the junction is less critical than the volume of material introduced into the junction. In cross section, the cone may be seen to resemble the wedge of Sensiper's wideband design. The aspect presented to the *H* arm, however, differs somewhat from the wedge. The cone becomes a section of reduced impedance line which is a half wavelength long, and is therefore not seen from the *H* arm. With the *E* arm matched by the cone, a suitable element affecting only the *H* arm is the "post" of the early designs. Its height and distance from the back wall of the junction are adjusted for match. Since the cone location is not critical axially, it is made concentric with the pin in order to obtain a simple form for the insert. With the addition of a thin resonant window to double-tune the *E* arm, the structure and performance shown in Figs. 4 and 5 is achieved. Over the 12 per cent *X* band, reflection is within 1.2 db swr (1.15 vswr) in both the *E* and *H* arms. A consequence of this match is isolation of over 35 db between collinear side arms. The *E-H* arm isolation is, of course, limited only by constructional symmetry of the junction; values of over 50 db over the band have been obtained in our models.

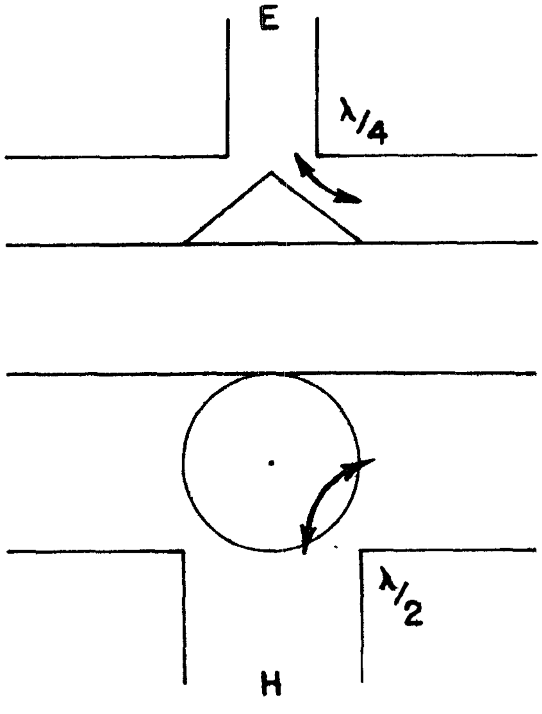

Fig. 3—Cone for matching *E* arm of hybrid tee.

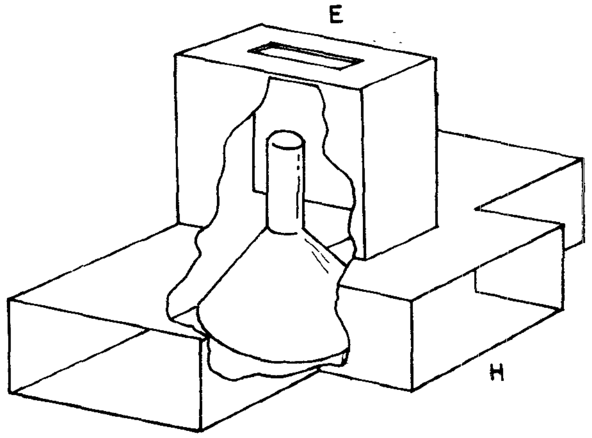

Fig. 4—Waveguide hybrid tee (WL model 201)

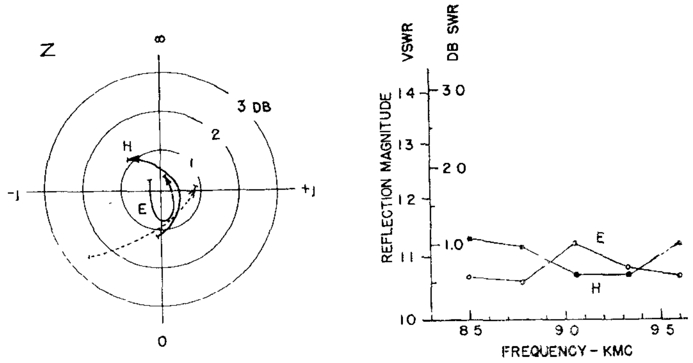

Fig. 5—Reflection of model 201 hybrid tee.

When the pin is modified into the form of a rounded fin and the resonant window is widened as shown in

Fig. 6, a high-power design is obtained, with performance equivalent to that previously described. Over the 12 per cent *X* band, the *E* arm of this junction has been found to carry pulse power of up to 1 mw without breakdown. (See Fig. 7.)

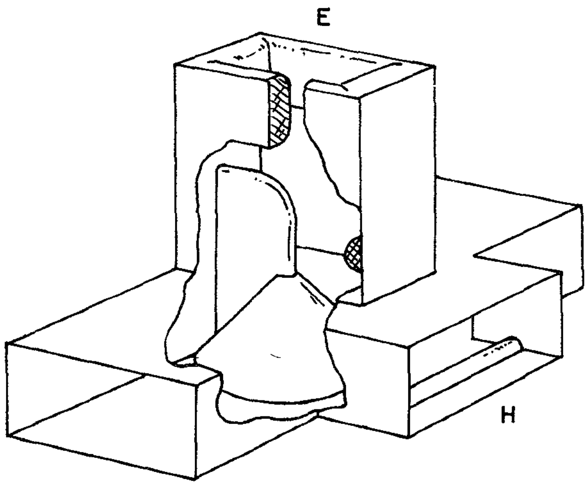

Fig. 6—High-power waveguide hybrid tee (WL model 120).

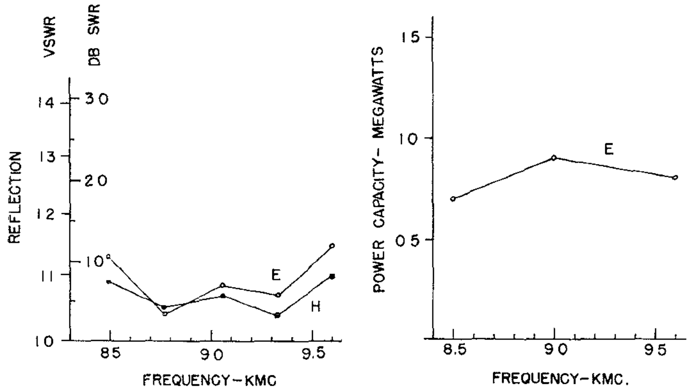

Fig. 7—Reflection and power capacity of model 120 hybrid tee.

Even higher power capacity has been attained with another structure, the *E*-plane forked hybrid.[2] In this junction, shown in Fig. 8, the "side" arms become parallel and are brought out in a direction opposite to the *E* arm. The *E* arm here feeds a guide having a thin partition in an equipotential plane; there is very little reduction of power by such a structure. Power tests of the *E*-plane fork over the 12 per cent *X* band indicate a pulse-power capacity of up to 1.6 mw in the *E* arm. The reflection of this junction, when combined with suitable adapters to bring all ports to normal waveguide size, is within 1.0 db swr (1.12 vswr), as shown in Fig. 9.

Another configuration of particular convenience is the *H* plane fork shown in Fig. 10. The perpendicular pair of ports are easily accessible; the other pair, which are adjacent in the *H* plane, provide a compact connection

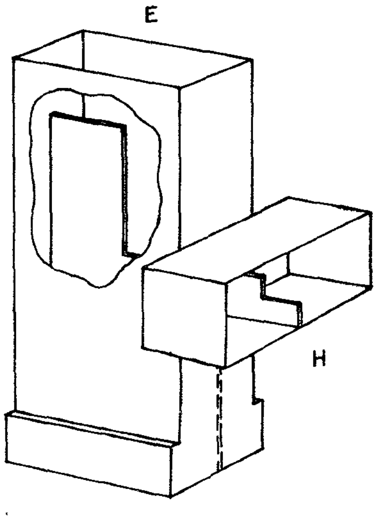

Fig. 8—*E*-plane forked hybrid (WL model 294).

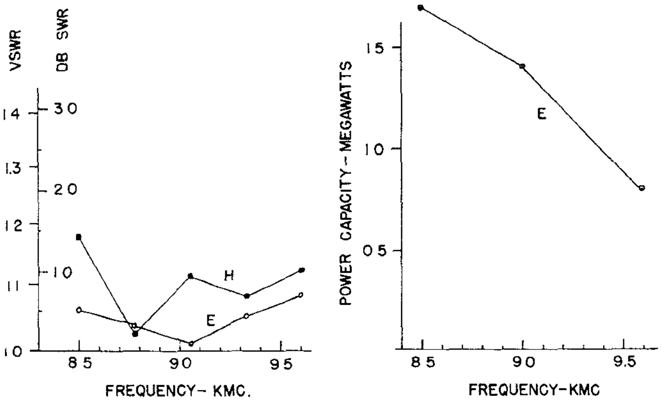

Fig. 9—Reflection and power capacity of model 294 forked hybrid.

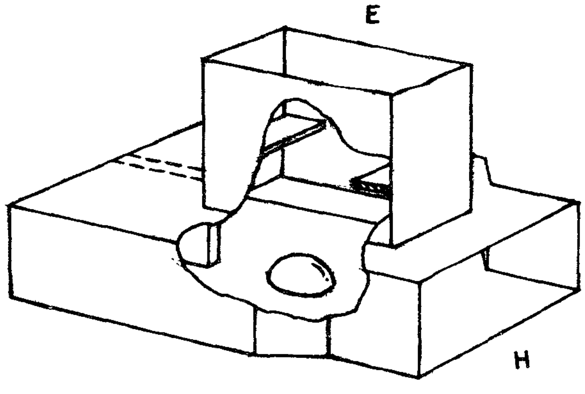

Fig. 10—*H*-plane forked hybrid (WL model 202).

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[2] W. K. Kahn, "E-plane forked hybrid-T junction," IRE Trans., vol. MTT-3, pp. 52–58; December, 1955.

to parallel antenna feeds, balanced mixers, or circulator elements. A similar structure has been developed by the Hughes Aircraft Co., and is presently being manufactured by Airtron. In the design shown here, the matching elements, which consist of a small round bump in the junction and an inductive iris in the *E* arm, achieve match within 0.8 db swr (1.10 vswr) in the *E* arm, and within 1.6 db swr (1.20 vswr) in the *H* arm, over the 12 per cent *X* band (see Fig. 11).

All the designs described have been carried to completion in one particular waveguide size (RG-51/U); the principles, however, are adaptable to any other size desired. By choosing a type of junction with inherent isolation in one pair of arms, it is necessary only to match that pair while maintaining symmetry in order to complete the junction design. The basic matching element for the *E* arm is a space-filling insert which acts as a power-divider; for the *H* arm, a resonant stub which couples the *H* arm to the side arms. Further matching may be achieved by introducing reactive irises or resonant windows in the *E* and *H* arms. Any symmetrical position of the side arms can be incorporated into a matched design; the extreme positions are represented in the designs described.

These design principles have resulted in waveguide hybrid junctions with simple matching elements, having good impedance match, isolation in both pairs of arms, and high power-handling capability.

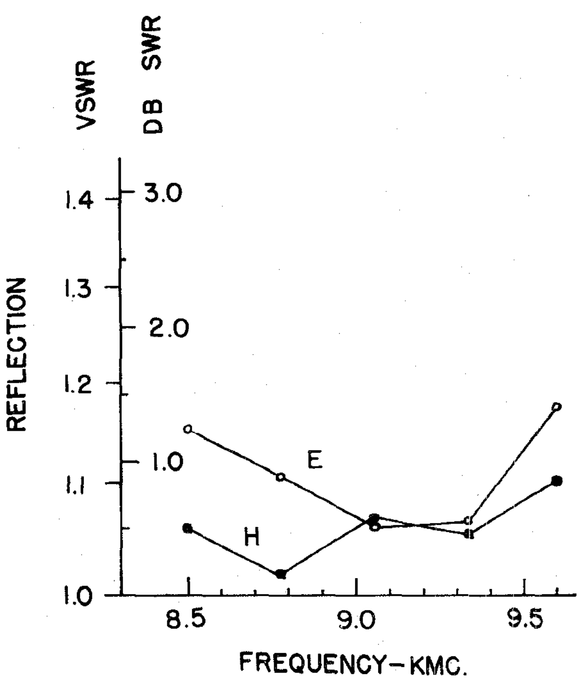

Fig. 11—Reflection of model 202 forked hybrid.

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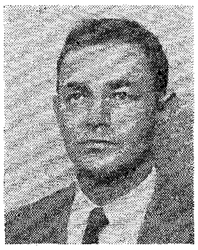
Helmut M. Altschuler (S'47–A'49–M '54–SM'55) was born in Germany, in 1922. He received the B.E.E. degree in 1947 and the M.E.E. degree in 1949 from the Polytechnic Institute of Brooklyn, New York, where he is continuing his graduate studies at the present time.

In 1947–48 Mr. Altschuler held a Research Fellowship at the Microwave Research Institute of the Polytechnic Institute of Brooklyn, and since then has been employed there, presently in the capacity of research associate.



H. M. Altschuler

His work has been concerned chiefly with the development of impedance meters, microwave measurement techniques, and equivalent network representations.

Mr. Altschuler is a member of Sigma Xi and Eta Kappa Nu.