II-6 OPTIMAL 3-PORT POWER DIVIDERS DERIVED FROM HYBRID-T PROTOTYPES

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This paper deals with 3-port power dividers which are optimal in the sense of excellent impedance match at all ports, low insertion loss in the normal mode of operation, and high isolation between the output ports. These optimal 3-port characteristics are in large measure common to those of 4-port hybrid-T junctions with a terminated sum or difference port; furthermore, the design of these optimal 3-ports may be derived from corresponding terminated hybrid-T prototypes. Their major advantages over the latter reside in relative compactness and/or simplicity of structure. The discussion here emphasizes a unified approach applicable to the design of a whole class of junctions; in fact, three such power dividers were designed, constructed, and tested.

The excellent performance, relative compactness and relatively light weight of these matched 3-port power dividers (with internal dissipative elements) have claimed considerable recent attention; corporate-feed networks of large array antennas provide one significant application. A particular form, comprising a symmetric E-plane bifurcation of rectangular waveguide, a multiple stage impedance matching transformer and a dissipative element in the plane of the bifurcation is now available commercially [1]. A junction similar to the one just described, another having the external outline of a conventional E-plane T in rectangular waveguide and a third junction having an outline of a coaxial-line T were investigated in connection with studies leading to the Master's degree at the Polytechnic Institute of Brooklyn [2], [3], and [4]. Only the last of these studies has been briefly reported in the literature [5].

The design philosphy exploited in this paper is based on a precise formulation of the concept that these lossy 3-port devices are equivalent to lossless 4-port hybrid-T junctions with terminated inaccessible difference ports. If it is stipulated that the 3-port power divider and its hybrid prototype are ideally symmetric, then both of these devices can be represented by the equivalent circuits shown in Fig. 1. In Fig. 1(a), the equivalent circuit of the prototype hybrid, originally derived in [6], is represented by an ideal hybrid and two 2-port networks; one is located in the sum arm and the other is located in the difference arm. The ideal hybrid-T properties are: all four ports impedance matched; opposite ports isolated and power input at any port divides exactly evenly between the two adjacent ports. The characteristics of the two 2-port networks represent the departures of the properties of the prototype hybrid from those of the ideal hybrid. Thus, the practical problems of designing a hybrid junction are reduced to: (1) maintaining symmetry and, (2)

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simultaneously eliminating the sum and different port reflections (making the two 2-ports as nearly equivalent to lengths of line as possible). The design of the optimal 3-port power divider, is completed by judiciously introducing the termination as a dissipative element into the junction itself. The associated symmetry properties of the fields remain the key to modal separation of the effect of dissipation within the junction. Several illustrative examples of this process are provided. If symmetry has been maintained and the input port and the inaccessible port are matched, the resulting lossy 3-port illustrated in Fig. 1(b) will exhibit the optimal properties defined earlier. It is emphasized here that the optimal 3-port power divider is truly distinct from its 4-port prototype, since the internal difference port is in principle inaccessible.

Fig. 2 illustrates the development of the E-plane bifurcation type waveguide power divider. The basic E-plane forked hybrid is presented in Fig. 2(a). The addition of a termination to the sum or H-arm forms a lossless 4-port power divider; it is shown in Fig. 2(b). Finally, the optimal 3-port is achieved by eliminating the sum port arm and bringing the termination into the junction along the symmetry plane as shown in Fig. 2(c). Cohn [1] has obtained excellent 3-port characteristics over a full waveguide band, while Heimer [2] has independently proved feasibility with a relatively simple configuation. Cohn's design, which is now available commercially, has the following 3-port characteristics; over the frequency band from 8.2 to 12.4 GHz., the VSWR at any port is less than 1.08:1, the power division is equal to 3.15 db and the isolation between output ports is greater than 30 db.

Fig. 3 illustrates the development of the E-plane T type waveguide power divider. The prototype hybrid-T takes the most conventional form presented in Fig. 3(a). The addition of a termination to the sum or H-arm forms a lossless 4-port power divider; it is shown in Fig. 3(b). Finally, the optimal 3-port is achieved by eliminating the difference port arm and simultaneously bringing the termination into the junction along the symmetry plane as shown in Fig. 3(c). Hirsch, [3] who used a simple semi-cylindrical matching bump appropriately located along the symmetry plane, also obtained good results. Over the 8.5 to 9.6 GHz, vand, the VSWR at the input port is less than 1.2:1, the VSWR at either output port is less than 1.4:1, the power division is equal to 3.3 db and the isolation between output ports is greater than 20 db.

Fig. 4 illustrates the development of the balun-T type of power divider applicable to any type of TEM transmission lines configuration which can be designed to propagate both balanced and unbalanced modes. The basic balun-T junction is illustrated in Fig. 4(a). The addition of the termination to the difference port arm forms a lossless 4-port power divider; it is illustrated in Fig. 4(b). Finally, the optimal 3-port is achieved by eliminating the difference port arm and bringing the termination into the junction along the symmetry plane as shown in Fig. 4(c). Parad and Moynihan [7] have developed this type of junction in strip-line. David, [4] and [5] has constructed a similar junction in coaxial-line, however, he has obtained a significant increase in the bandwidth of this type of optimal 3-port by double-tuning the difference port matching scheme. Fig. 5 presents the measured loci of the input and output port reflections; also shown are sketches of the power dividers showing the reference planes for both loci. Over the octave hand from 1.0 to 2.0 GHz., the VSWR at any port is less than 1.4:1, the power division is equal to 3.0 db, and the isolation between output ports is greater than 19 db.

It is anticipated that an understanding of the design philosophy discussed herein will stimulate development of additional types of 3-port power dividers and facilitate improvements in existing types.

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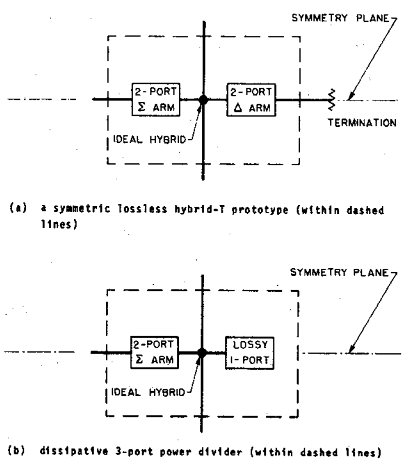

FIG. 1 - Development of the class of optimal 3-port power dividers from terminated symmetric hybrid-T prototypes.

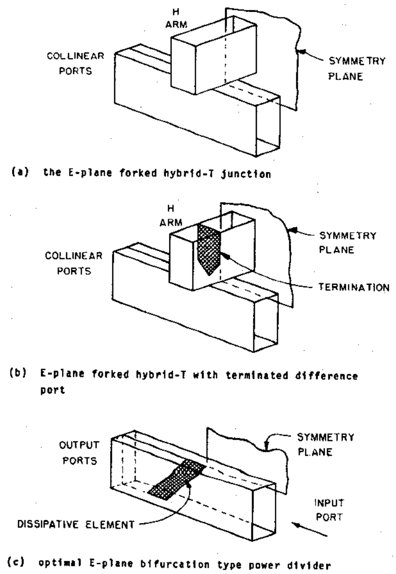

FIG. 2 - Development of the E-plane bifurcation-type waveguide power divider.

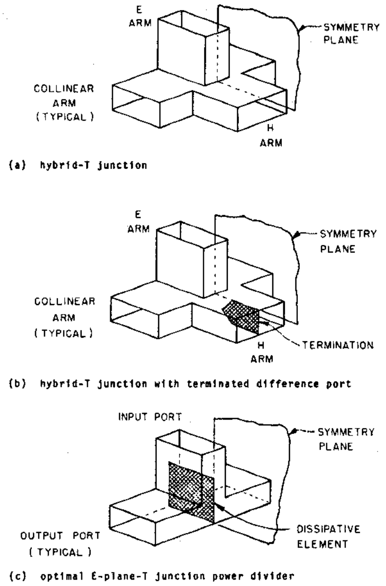

FIG. 3 - Development of the E-plane T type waveguide power divider.

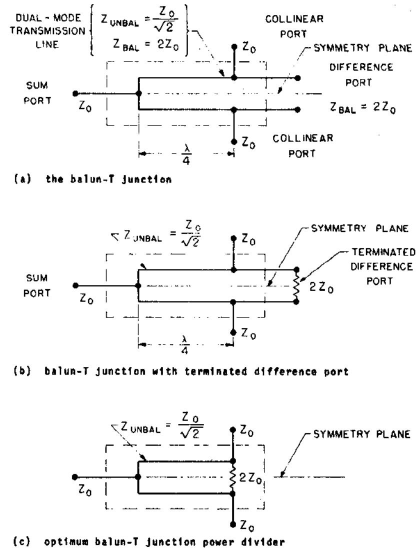

FIG. 4 - Development of the balun-T type of power divider.

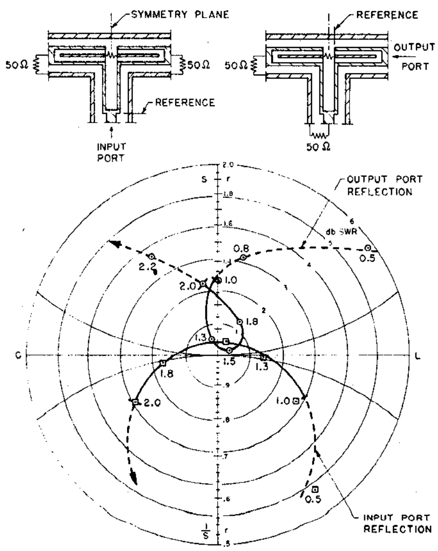

FIG. 5 - Measured input and output reflection loci, wideband coaxial-line power divider.