A Compact Planar Magic-T Junction with Aperture-Coupled Difference Port

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***Abstract*—The operating principles of a compact planar magic-T junction are described and experimentally validated. The distinguishing feature of this component is the placement of the difference port on a layer separated from the other three ports by a ground plane. Moreover, the two parts of the component are electromagnetically coupled through a slot-aperture in the ground plane. The component is inherently multilayer, i.e., the transition between the circuit layers is a functional part of the device. The tested microstrip prototype performs well over a frequency range of about 40%.**

***Index Terms*— Hybrid junctions, passive circuits, microwave integrated circuits.**

I. Concept Description

IN MANY planar phased-array architectures, complex circuits required to support each radiating element are constrained to relatively small areas. To achieve the required functionality the components are distributed over several layers, interconnected by means of vias and aperture couplers. The interconnects are typically treated as separate elements. However, their integration into circuit components results in more compact architectures.

To demonstrate this approach, a 180°-hybrid (magic-T) microstrip junction, incorporating an aperture interconnection between two layers is demonstrated.[1] The geometry is shown in Fig. 1. The microstrip line on the lower substrate is coupled to a slot-aperture and is terminated on the same layer by an open-circuit stub. This line will be shown to correspond to the difference arm of the magic-T. The other three magic-T ports are located on the second layer in the arrangement shown.

Two basic observations, summarized below, were used to develop the concept and guide the design of the component.

1) Analyses of transverse slot-coupled parallel microstrip lines have shown that a signal supplied to a line on one layer can be coupled equally in magnitude and 180° out of phase to the two microstrip arms on the other layer. This fact was used in designing the difference port of the hybrid.
2) It has also been observed, and can be qualitatively explained by utilizing field-symmetry arguments, that two microstrip lines (or other lines with the same fundamental-mode-field symmetries) which are mutually perpendicular cannot be significantly coupled through a narrow slot aperture if the slot is longitudinally disposed in the symmetry plane of one of the lines. This observation provided the mechanism for the decoupling of the sum and the difference ports.

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[1] Patent pending.

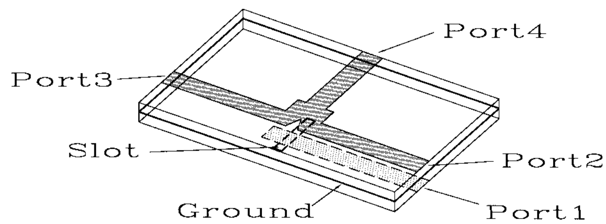

Fig. 1. Microstrip magic-T junction with a slot-coupled difference arm.

The initial design of the magic-T junction was carried out in two independent stages. In the first step, utilizing analytical results presented in [1], an aperture-coupled microstrip-to-microstrip power divider was designed. Its operational characteristics were described in item 1) above. The resulting structure included ports designated by 1 (difference arm), 2, and 3 in Fig. 1. In the second step, arm 4 was attached to the microstrip line containing ports 2 and 3 in a tee-junction arrangement. A quarter-wave transformer was used to improve the match of line 4 to the tee-junction.

The initial design was analyzed using a commercial full-wave code [2]. After several small perturbations, including a compensating triangular groove in the tee-junction, the final configuration of Fig. 1 was obtained.

II. Component Response

To validate the concept, a low-frequency prototype was constructed using the 62-mil-thick $\epsilon_r = 2.2$ (Rogers-5880) substrates on both sides of the ground plane. All input–output lines were 196-mil wide (50 Ω). The tee-junction matching-transformer was 360 mil in both width and length, the latter measured from the edge of the transverse line to which it was attached. The slot-aperture was 600-mil long and 60-mil wide. The open-circuit stub used to terminate the difference arm was 280 mil with respect to the aperture center.

The component was designed to operate around 6 GHz, and its performance was simulated and measured over the 3.5–8-GHz frequency band. Two-port measurements were performed for several port combinations, with the remaining ports matched at the SMA connector coaxial inputs. A TRL calibration was carried out to remove the effects of the SMA-to-microstrip transitions. However, the calibration was in effect only at the ports connected to the network analyzer. The transition discontinuities were present at the terminated ports

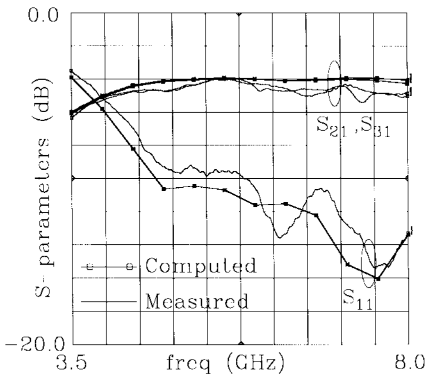

Fig. 2. Frequency dependence of $|S_{11}|$, $|S_{21}|$, and $|S_{31}|$ for the tested component prototype.

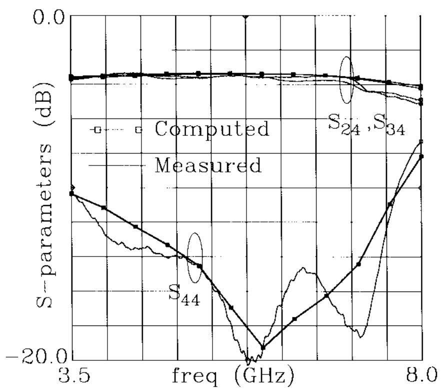

Fig. 3. Frequency dependence of $|S_{44}|$, $|S_{24}|$, and $|S_{34}|$ for the tested component prototype.

and manifested themselves in the oscillations observed in the measured traces and slightly larger than expected insertion loss values.

Measured and computed magnitudes of some S-matrix elements are presented in Figs. 2 and 3. The operational bandwidth of the device is largely determined by the response of the slot-coupled microstrip lines. The 2 : 1 SWR lower band edge of the S_{11} response (Fig. 2) is approximately 4.4 GHz. At the high end of the spectrum, the radiation losses associated with the slot became significant. Moreover, the sum-port match (S_{44}, Fig. 3) deteriorated. Overall, the measured prototype had the following characteristics over a 4.4–6.5-GHz band of frequencies:

- better than 2 : 1 SWR response in the sum and difference ports;
- with the excitation at the difference-port and signals measured at ports 2 and 3, the insertion loss was $<$1.5 dB and the phase difference was 180°, with the maximum (over the frequency range) imbalance between ports 2 and 3 at 0.3 dB in the magnitude and 2° in the phase;
- when the sum-port was fed the insertion loss was $<$0.5 dB and the phase difference was 0°, while the maximum imbalance between ports 2 and 3 was 0.2 dB in the magnitude and 2° in the phase;
- the isolation between the sum and the difference ports was better than 33 dB.

The performance of the actual device, de-embedded from the connectorized fixture, is expected to be even better, as indicated by the results of the full-wave simulation. The primary reasons for the discrepancies between the computed and the measured data are incomplete de-embedding of the ports and fabrication errors. Particularly significant among the latter are misalignment of the layers and air-gaps between the ground planes of the two substrates.

III. Conclusions

A compact planar magic-T junction was designed and fabricated. The component is inherently multilayer in structure, taking advantage of the slot-interconnect to synthesize the required characteristics. The concept lends itself to implementation in other transmission lines having compatible modal-field characteristics. Increased fabrication accuracy and impedance-matching improvements to the basic design are expected to widen significantly the useful bandwidth of the microstrip version of this component.

References

[1] M. Davidovitz, R. A. Sainati, and S. J. Fraasch, “A noncontact interconnection through an electrically thick ground plate common to two microstrip lines,” *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 753–759, Apr. 1995.

[2] *Hewlett-Packard Momentum User’s Guide*, version 7.0.