CAD of Magic Tee with Interior Stepped Post for High Performance Designs

Ralf Beyer* and Uwe Rosenberg**

*Mician GbR, 28195 Bremen, E-mail: beyer@mician.com
**Marconi Communications GmbH, 71522 Backnang, E-mail: uwe.rosenberg@ieee.org

Abstract — **A CAD - based on the Finite Element / Mode Matching (FE/MM) method - is introduced for high performance Magic Tee designs that make use of an interior stepped post discontinuity in the branching region. The theoretical considerations of the approach are outlined. For validation a Magic Tee is designed and realized at 12 GHz exhibiting high performance properties over 14 % bandwidth. Accurate coincidence of computed and measured responses verify the CAD method.**

I. Introduction

Waveguide hybrid junctions are widely used in microwave and millimeter wave systems for power distribution (combination) and multiplexing purposes - in the latter case mainly in combination with filters [1]. Among them, the hybrid T-junction type (which is well known as Magic Tee) has attracted special interest for many applications since the post war period, due to its special 0 and 180 degree phase properties. First sophisticated designs were introduced in the 50^{th} [2], [3], with shaped discontinuities inside the 4-port branching region. After a long period Magic Tees regained interest of researches in the early 90^{th} when emerging field theoretic analysis methods were applied to the design of that special structure [4], [5], [6], [7]. However, most of the methods restrained the analysis of the empty Magic Tee branching which is commonly of secondary importance due to its poor characteristics. A simple post discontinuity inside the branching region was only considered in [7]. Despite of increased performance in that case above the other solutions, the results were still not satisfactory for practical applications.

This paper introduces a CAD approach that provides the design of Magic Tees with an interior stepped post (cf. Fig. 1). It is based on the 2D Finite Element / Mode-Matching method (FE/MM) [8], [9] that is properly embedded in an overall 3D waveguide CAD tool. The approach has been applied to the design of a Magic Tee with an interior post with stepped diameters along its height. Accurate coincidence of computed and measured high performance properties which are comparable to those of the established traditional designs (e.g. [3]) validate the advanced design method.

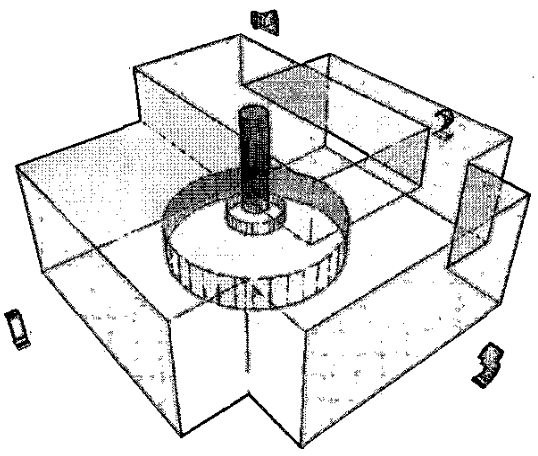

Fig. 1. Sketch of Magic Tee with interior stepped post

II. Theory

For application of the well established FE/MM method [8], [9] the device under consideration is expanded with rectangular waveguide sections at ports 1-3, as shown in Fig. 2. This new device consists only of simple step discontinuities of homogeneous waveguide sections, and thus the general scattering matrix or admittance matrix can be computed by application of the standard mode-matching method. The additional waveguide sections transform the absorbing boundary conditions at the side coupled ports 1 to 3 into homogeneous boundary conditions, and therefore avoid any frequency dependent FE calculations.

The FE/MM method is applied from top to bottom of the Magic Tee structure - starting with an analytical rectangular waveguide section at port 4, followed by FE-sections for the stepped post inside the rectangular and T-shaped waveguide

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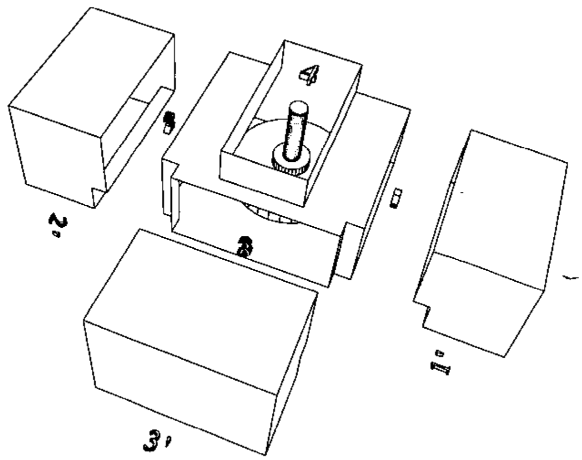

Fig. 2. Device modification suitable for application of the standard FE/MM method and de-embedding technique for the side coupled waveguide ports

and finally jumping to the 3 parallel rectangular waveguide sections for ports 1 to 3.

The final scattering matrix of the Magic Tee results from de-embedding the additional 90^0 waveguide corners - similar like de-embedding transitions in a network analyzer measurement. However, for this extraction more modes than just the fundamental mode are necessary, since the waveguide corners may have transmission zeros for the fundamental mode inside the frequency band under consideration.

This procedure can be applied either to the scattering or admittance matrix in a similar fashion. Formulas for extraction of the scattering matrix are given in [10]. The waveguide corners themselves can be calculated very efficiently by simple analytical techniques [11]. Although the use of the admittance matrix is faster (less matrix-/matrix-operations), the savings in CPU-time are almost negligible (less than few ms/frequency). Most computational effort is required for calculation of the step discontinuities inside the T-waveguide sections, due to the higher number of considered modes.

Limitations of this method are given by the attenuation of the evanescent modes inside the waveguide corners. Guided modes can be accurately extracted up to levels of 40 to 50 dB return loss, depending on the accuracy of the calculation of the FE/MM device. For higher order evanescent modes the system of equations for the extraction becomes rapidly singular and yields unreliable results. The best choice for the extraction of the fundamental TE_{10}-mode of a standard waveguide in the nominal band is the set TE_{10}, TE_{01}, TE_{20}, TE_{11} and TM_{11} modes.

Due to the symmetry of the structure, the calculation can be split into an even (magnetic wall in the symmetry plane) and an odd part (electric wall in the symmetry plane). This reduces memory and CPU-time requirements, since the CPU-time grows faster than $O(n)$, where n is the number of considered modes or the number of triangles in the FE calculation.

The final scattering matrix can be composed of the even (index e) and the odd (index o) scattering matrix in the following manner:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{2}(S^e_{11} + S^o_{11}) & \frac{1}{2}(S^e_{11} - S^o_{11}) & \frac{1}{\sqrt{2}} S^e_{13} & \frac{1}{\sqrt{2}} S^o_{14} \\ \frac{1}{2}(S^e_{11} - S^o_{11}) & \frac{1}{2}(S^e_{11} + S^o_{11}) & \frac{1}{\sqrt{2}} S^e_{13} & -\frac{1}{\sqrt{2}} S^o_{14} \\ \frac{1}{\sqrt{2}} S^e_{13} & \frac{1}{\sqrt{2}} S^e_{13} & S^e_{33} & 0 \\ \frac{1}{\sqrt{2}} S^o_{14} & -\frac{1}{\sqrt{2}} S^o_{14} & 0 & S^o_{44} \end{bmatrix}$$

During the optimization of the Magic Tee device, there's no need to re-calculate the modes of the T-shaped waveguide sections, as long as only the heights of the stepped post are varied.

III. Design and Realization

A Magic Tee has been designed and realized at Ku-band to verify the above approach. The basic structure comprises the classical four-port branching of a Magic Tee with an interior post exhibiting stepped diameters - decreasing from the bottom wall towards the opposite 4th (E-plane) interface port. All waveguide ports of the branching consider directly interfacing of the standard WR75 waveguide cross sections. Hence, these dimensions also determine the height and width of the branching region, since no other discontinuities than the stepped post are considered. Thus, only the post has been optimized to achieve the desired high performance properties, this is its location along the symmetry axis of the overall structure and its stepped sections with the respective diameters and heights.

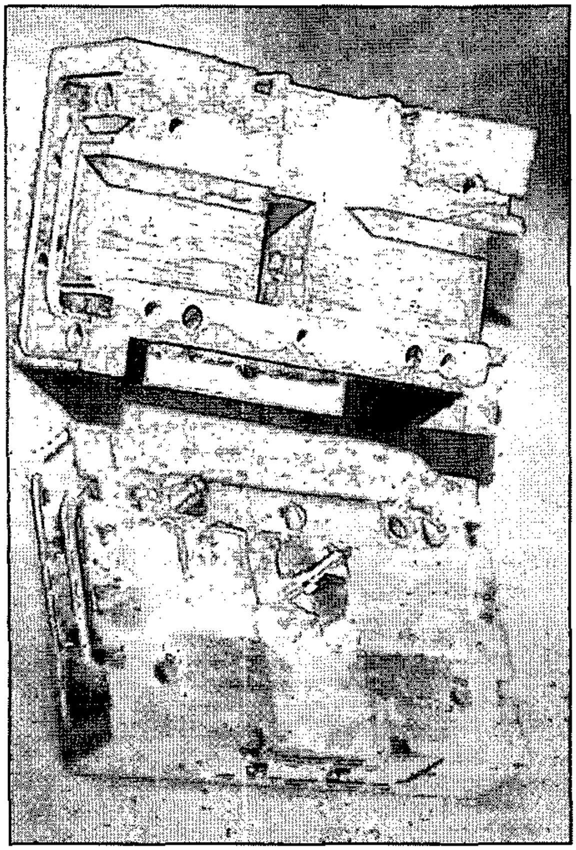

Fig. 3. Photograph of the Magic Tee reference hardware

The design has been performed for a Magic Tee at 12 GHz with a bandwidth of more than 10 %. The aspired performance is obtained by the initial branching structure with an interior post having three concentric stepped sections as depicted in Fig. 1. For experimental verification, an existing hollow branching region has been equipped with the special shaped post at the computed location. A photograph of the hardware is shown in Fig. 3.

Computed and measured responses exhibit accurate coincidence, as the results in Figs. 4 to 6 show. In detail, the return loss at all ports is more than 20 dB from 11.2 to 12.9 GHz - that represents a bandwidth of 14 %. Within this band accurate 3 dB power splitting properties from port 1 (and 2) to 3 and 4, respectively (cf. Fig. 6), and high isolation between ports 1 and 2 (Fig. 4) is obtained. The slight deviations of theoretical and measured curves can be attributed to manufacturing tolerances which are mainly dedicated to an offset location of the post from the symmetry axis in the order of 0.05 mm. An indication for this is the measured finite isolation (more than 32 dB) between ports

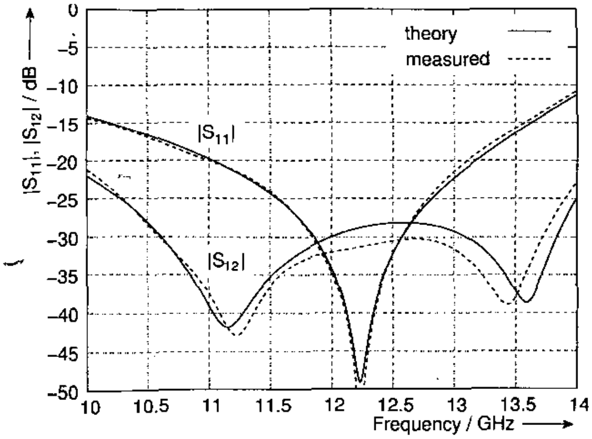

Fig. 4. Ku-Band Magic Tee with stepped post - return loss and isolation characteristics: computed (solid lines) and measured (dashed lines)

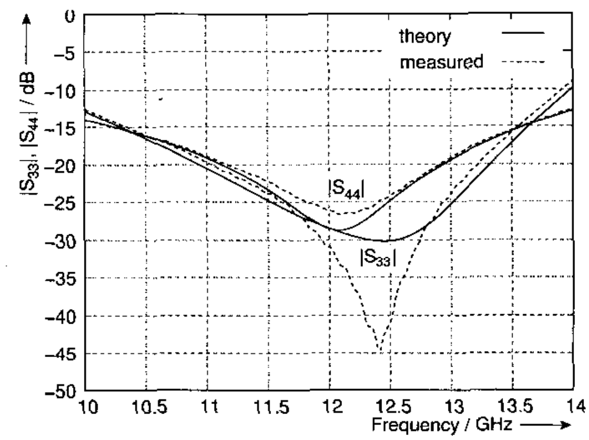

Fig. 5. Ku-Band Magic Tee with stepped post - return loss characteristics: computed (solid lines) and measured (dashed lines)

3 and 4 - that is theoretically infinity, due to orthogonal orientation.

IV. Conclusion

The FE/MM CAD method has been applied to the design of high performance Magic Tees exhibiting an interior stepped post in the branching region. Theoretical considerations of this approach have been introduced for this particular structure. To verify the method a Magic Tee has been designed at 12 GHz. The diameters and the heights of the stepped post and its location on the symmetry axis have been optimized in the classical 4-port branching with WR75 waveguide interfaces. High performance properties have been obtained over 14 % bandwidth with the sole op-

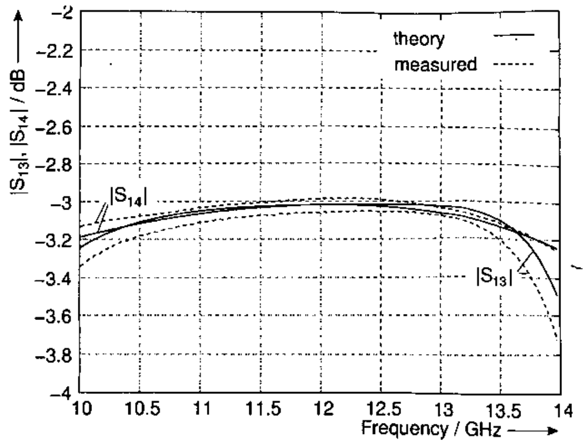

Fig. 6. Ku-Band Magic Tee with stepped post - power division characteristics: computed (solid lines) and measured (dashed lines)

timization of the post dimensions. Accurate coincidence of computed and measured responses of the realized Magic Tee proves the CAD approach. This Magic Tee design may be refined with irises at the branching ports, e.g., to enhance the bandwidth properties. It should be noted, that the introduced method can also be applied to other kinds of hybrid or multiport junctions with interior discontinuities, as for example, folded Magic Tees or OrthoMode Transducers (OMTs).

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