ELECTROMAGNETIC MODELLING OF MICROWAVE COMPONENTS CONSISTING OF RECTANGULAR WAVEGUIDES E-PLANE COUPLED BY A COAXIAL CAVITY

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ABSTRACT

Two mode-matching techniques for the numerical analysis of non-symmetric E-plane-coupled coaxial-cavity N-ports are presented. The first technique utilizes cartesian and cylindrical coordinate systems for waveguide-cavity interfacing. The second technique uses rectangular coordinates only and neglects the curvature of the coaxial cavity. Software for both models has been written for personal computers and requires only seconds for a complete analysis.

1. INTRODUCTION

Waveguide components consisting of radial or coaxial cavities with rectangular waveguide input/output ports connected in the E-plane find applications in many microwave systems. The well-known ring hybrid consisting of a coaxial cavity and four waveguide input/output ports is a typical example [1]. Of most recent interest have been symmetric N-ports consisting of a radial or coaxial cavity and E-plane-connected rectangular waveguides. When impedance matched, these symmetric N-ports exhibit properties such as constant power division and constant phase difference between different waveguide ports over a relatively large frequency range. Because of these properties they can be exploited in power combiners and dividers [2]. It has also been demonstrated that these components can be used to build microwave and millimeter-wave six-port network analysers [3, 4].

In order to obtain a predictable and timely design of waveguide N-ports, the engineer usually has to rely on suitable computer-aided analysis techniques. Computer algorithms restricted to the analysis of symmetric N-ports have been presented in [5] and [6]. In [5], a non-standard but highly efficient mode-matching technique is used, while in [6], a computer-intensive least-squares boundary residual method is applied. Both methods solve for the scattering parameters of a symmetric E-plane-coupled waveguide N-port. However, for non-symmetric N-ports, such as the waveguide ratrace ring, efficient and accurate analysis algorithms have not previously been available.

This paper focuses on two types of mode-matching techniques for the analysis of non-symmetric E-plane-coupled coaxial-cavity N-ports. First, the efficient analysis technique of [5] is extended to cover cases involving non-symmetric radial E-plane devices. In parallel with this technique, an alternative method which ignores the curvature of the radial cavity is described. This second technique approximates the coaxial cavity by a cascade of straight sections of rectangular waveguide between standard E-plane T-junctions, with the ends joined via a hypothetical waveguide section of vanishing length.

2. THEORY

A. Circular Boundary Mode-Matching Technique (MMT #1)

This method utilizes the TE to x radial mode spectrum to obtain the fields in the cavity and in the waveguide regions, shown in Figure 1.

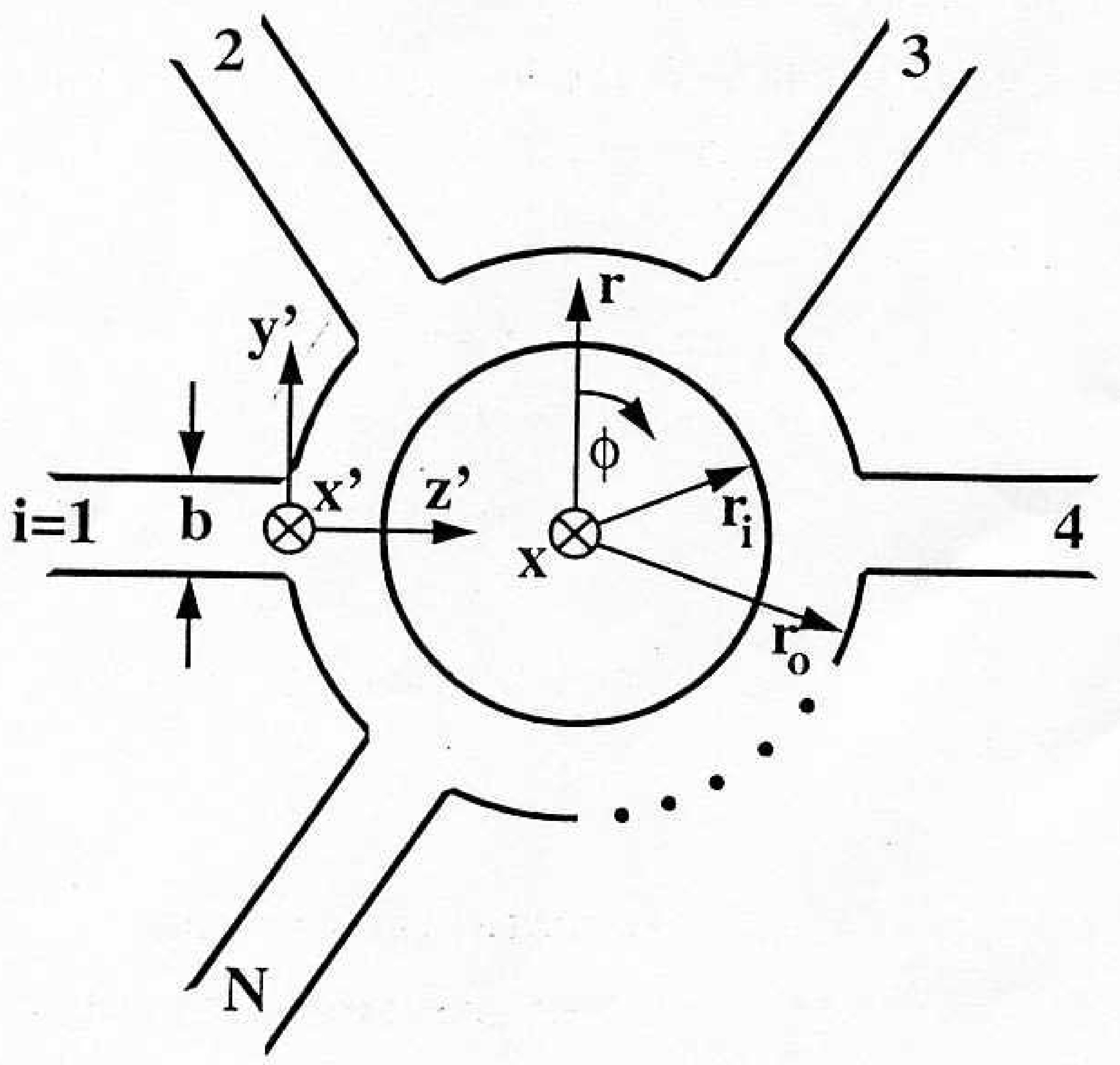

Fig.1 E-plane coaxial-cavity waveguide N-port.

To determine the scattering parameters, an electromagnetic problem is solved in which one of the input/output ports is excited while the remaining ports are match-terminated. The field in the cavity region is represented by TE to x radial modes which in turn are given in terms of special cylindrical functions. The x-component of the magnetic field in the waveguide regions is given in terms of rectangular waveguide modes but expressed in cylindrical coordinates r, φ, x. The expansion coefficients for the field in the cavity and waveguide regions are determined by imposing the continuity conditions for the tangential components of the electromagnetic field (the x-component of the magnetic field and φ-component of the electric field) at the common boundary $r=r_o$, between the cavity and waveguide regions. The required expressions for the φ-components of the electromagnetic field in the guides and the cavity are determined using the relationships between the x-and φ-components for the TE to x radial fields. As the continuity conditions are applied only along the circular boundary $r=r_o$, the field matching procedure is different from that described in [5] where the continuity conditions were applied at both the circular boundary $r=r_o$ for E_φ, and a rectangular boundary at $z'=0$ for H_x. This refinement obviates the need for the cylindrical function approximations which were required in [5]. On the other hand, the accuracy obtained by this manipulation is still equivalent to that obtained in [5].

The algebraic equations are produced by multiplying the continuity equations by the appropriate orthogonal functions, which are then integrated within the angular limits $0<\varphi\ <2$, and $\varphi_i-\varphi_o/2 < \varphi < \varphi_i + \varphi_o/2$, for the cavity and waveguide apertures respectively.

B. Straight-Waveguide Mode-Matching Technique (MMT #2)

The geometry for the straight-waveguide mode-matching technique, which is based on cascaded E-plane T-junctions, is depicted in Figure 2.

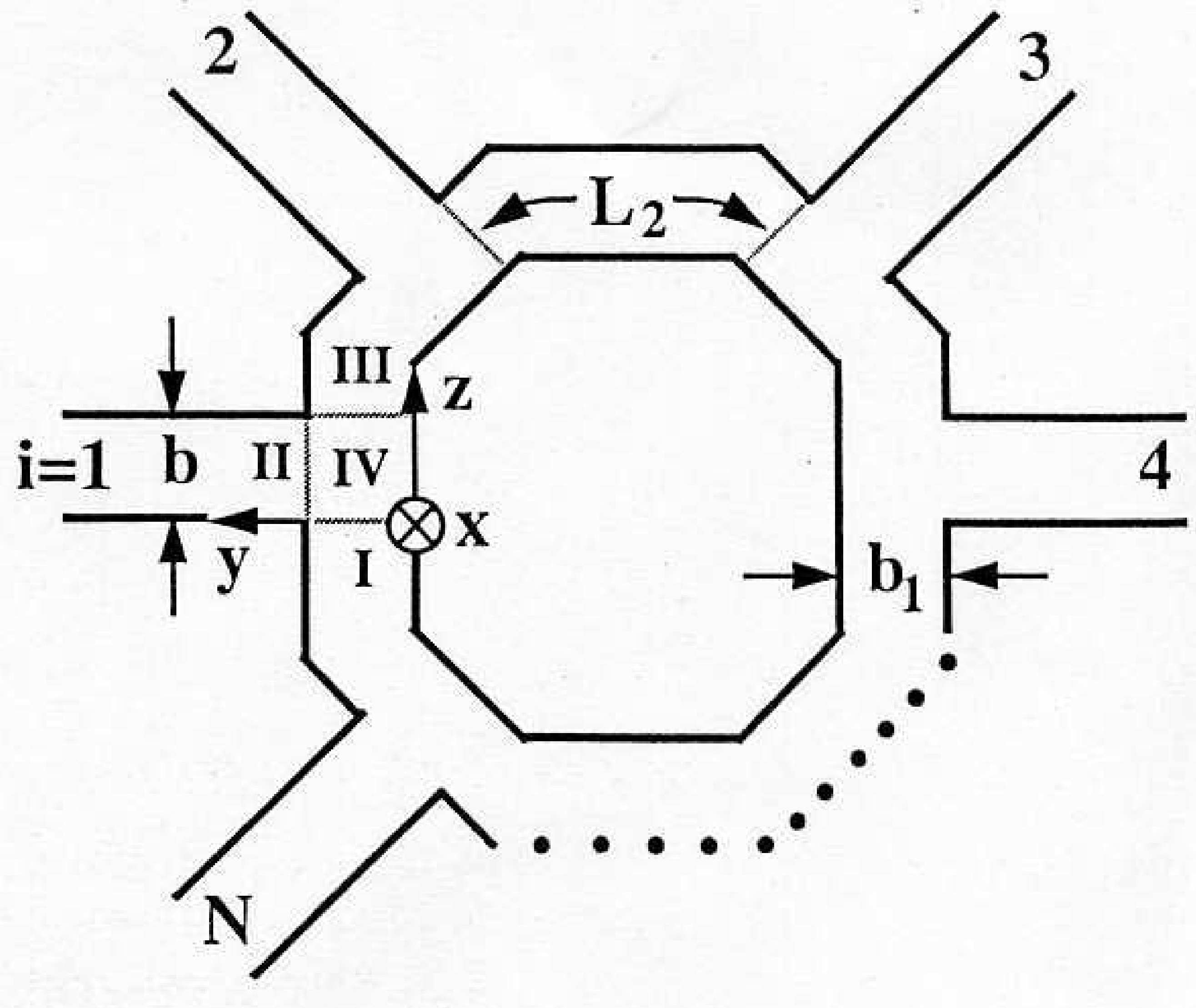

Fig.2 Geometry considered for the straight-waveguide mode-matching technique (MMT #2).

Note that the bends in waveguides, (shown here as 45°-bends) are neglected in this model.

As in the circular boundary mode-matching technique (MMT #1), the electromagnetic field in each of the three ports connected to an individual T-junction is derived from the x-component of a vector potential [1]. Matching the transverse electric and magnetic fields at the three interfaces leads to the generalized scattering matrix of the T-junction. The sections are cascaded using a general algorithm [1]. Finally, the input and output ports of the cascade are connected by a hypothetical waveguide of vanishing length to simulate the closed structure of the coaxial cavity.

3. RESULTS

An excellent agreement between MMT#1 (represented by different texture lines) and a finite-element analysis using High Frequency Structure Simulator, HFSS, by Hewlett Packard (symbols o ,□,■ ×) is demonstrated in Fig. 3a for the example of a 3λ /2 ring hybrid at X-band.

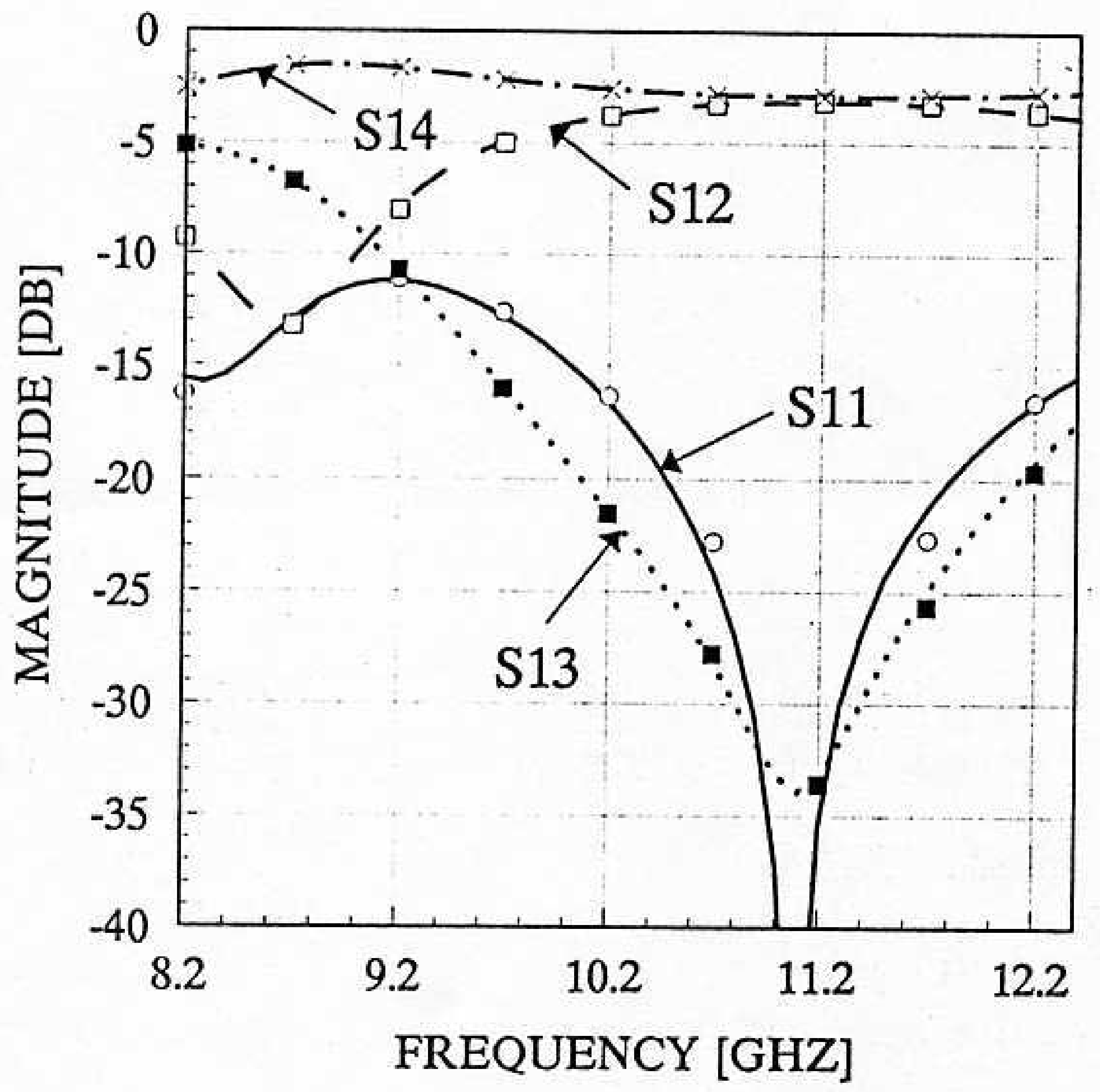

Fig.3a Comparison between MMT#1 and HFSS for the scattering parameters of a 3λ/2 X-band ratrace coupler. Dimensions [mm]: a=22.86, b=10.16, r_o=11.7, r_i=4.5. Ports at φ=0°, 60°, 120°,180°.

The second method investigated, MMT#2, produces only approximate values of the scattering matrix parameters for the 3λ/2 ring hybrid.

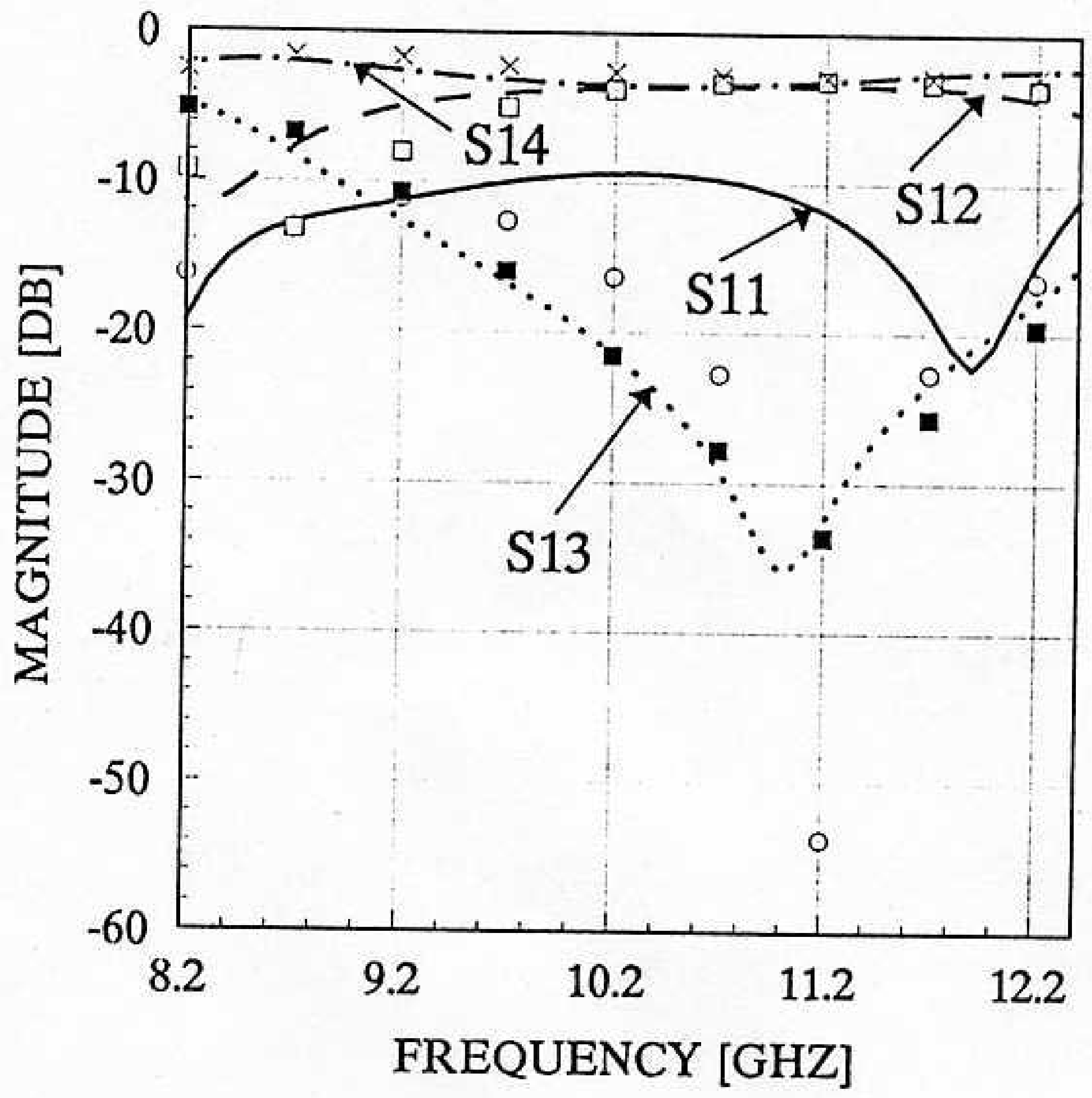

Fig.3b Comparison between MMT#2 and HFSS for the scattering parameters of a 3λ/2 X-band ratrace coupler. Dimensions as in Fig.3a.

The disagreement observed in Figure 3b, is especially apparent for the return loss (S_{11}). The small inner radius of the structure and the number of tightly cascaded T-junctions clearly demonstrate the limitations of this approach, particularly for wide-band applications. The disagreement in S_{11}, stems from the fact that the return loss at the input port strongly depends on the shape and curvature of the opposite wall of the waveguide T-junction (compare Fig. 2 with Fig. 1).

Figure 4 shows comparison between HFSS (MTT#1 produced almost identical results which are not shown here) and MMT#2 for a 9λ/2 ring hybrid. In this case, there is slightly better agreement between MMT #2 and HFSS. The reason for the improved accuracy of the MMT #2 results is that for the 9λ/2 ring hybrid, the curvature of the cavity is smaller than for the 3λ/2 hybrid and is therefore a better approximation to the straight waveguide T-junctions.

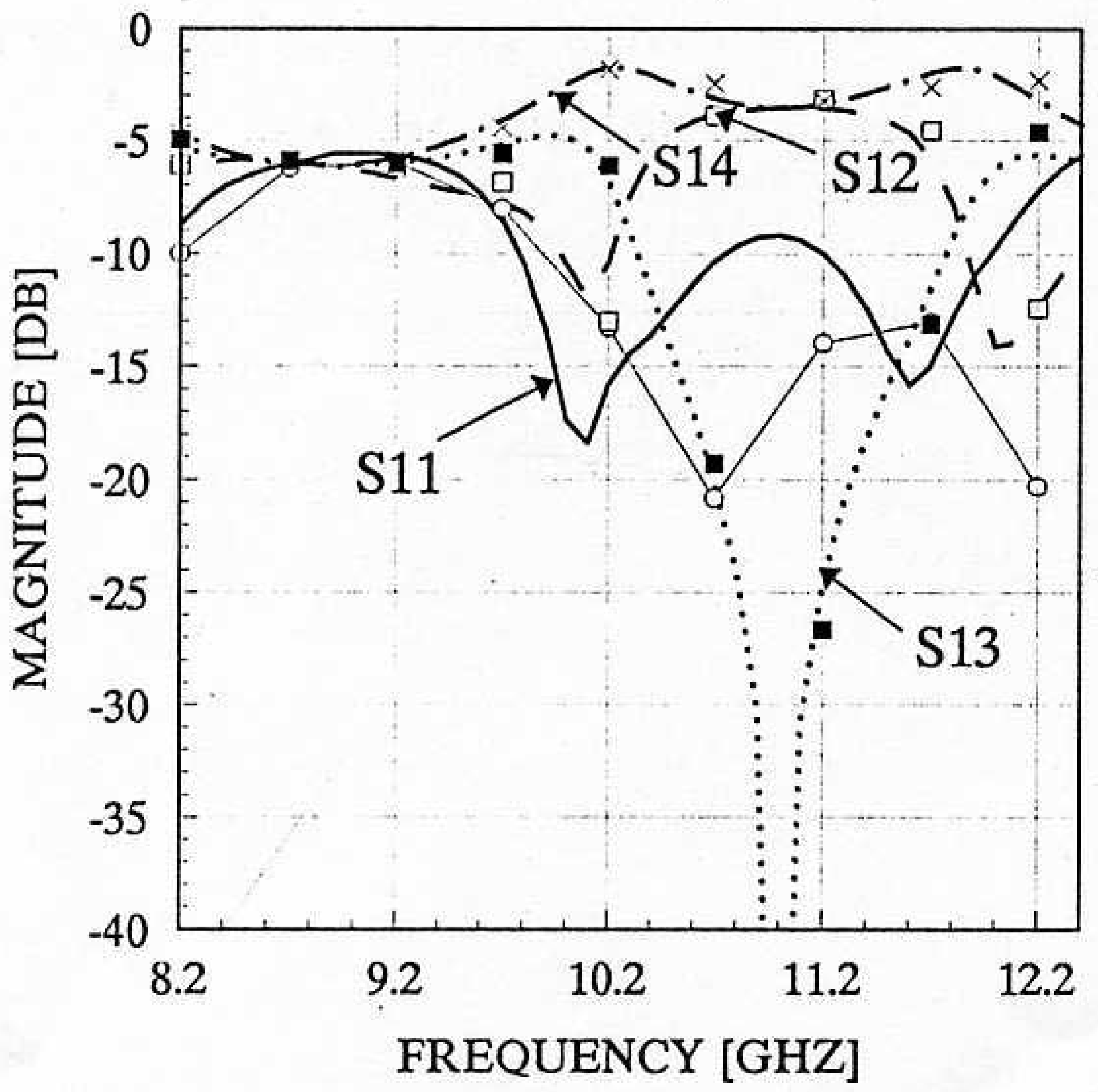

Fig.4 Comparison between MMT#2 and HFSS for the scattering parameters of a 9λ/2 X-band ratrace coupler. Dimensions [mm]: a=22.86, b=10.16, r_o=27.9, r_i=20.7. Ports at φ=0°, 60°, 120°,180°.

The advantage of both methods #1 and #2 compared with a finite-element routine, such as HFSS, is computational speed. For the analyses of the ratrace couplers with 100 frequency points, the circular boundary (MMT#1) and the straight-waveguide (MMT #2) mode-matching techniques required 70 and 60 seconds, respectively, on a 66 MHz PC. For the MMT#1, 30 cavity modes and 3 waveguide modes were found to be sufficient. For the MMT #2, 15 modes for the T-junction analysis and 5 modes for cascading individual junctions were sufficient. As a comparison, it took 1 hour for HFSS to produce a single frequency point, when operated on a SUN IPX 66 MHz workstation with the convergence criterion ΔS= 0.01.

4. CONCLUSION

This paper has presented two mode-matching techniques for the analysis of non-symmetric waveguide N-ports, which are E-plane-coupled via a coaxial cavity. Both techniques are operational on standard personal computers and provide results considerably faster than other methods on more powerful workstations. By comparison with data from a finite-element analysis, it has been demonstrated that, by virtue of its computational speed and accuracy, the circular boundary mode-matching technique (MMT #1) is the preferred choice for the design of radial waveguide power dividers. Within its limitations, the straight-waveguide mode-matching technique (MMT #2) can be applied as a first-order approximation.

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