THEORY AND EXPERIMENT ON RECTANGULAR COAXIAL LINE DISCONTINUITIES AND JUNCTIONS

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ABSTRACT. Step discontinuities and junctions in rectangular coaxial lines are analyzed both theoretically and experimentally. The theoretical approach is based on a modified field matching technique extended to 3-D problems for the analysis of multiaxial discontinuities. Experiments in the 2 to 6 GHz band show excellent agreement with the theoretical predictions.

1. INTRODUCTION

The Rectangular Coaxial Cable (RCC) has been proposed as an attractive transmission line for microwave circuits, specifically for beam forming networks (BFN) in communication satellites [1]. The RCC has good performances in terms of high Q and power handling capacity, associated with significant size reduction in comparison with the rectangular waveguide. In addition, because of the rectangular geometry, the RCC has mechanical advantages with respect to the conventional coaxial cable, and allows an entire network to be integrated on the same board.

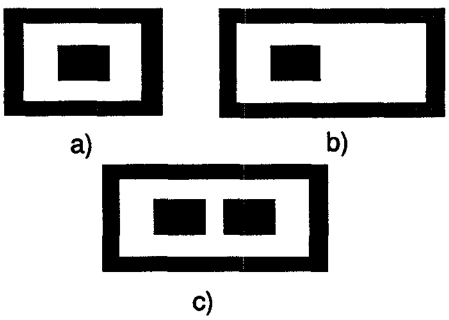

Fig. 1. Cross sections of various RCC configurations

Although this type of structure has been the subject of some investigations already many years ago [2], no information is available in the open literature as far as discontinuities are concerned. The modeling of discontinuities, however, is the basic step for the computer-aided design of the various components, such as couplers, power dividers, phase shifters, etc. used in the realization of beam forming networks (BFN). This paper presents a theoretical approach to the analysis of RCC discontinuities as well as some experimental data produced to verify the theoretical predictions.

2. MODELING OF RCC

Fig. 1 shows the cross sections of RCC configurations encountered in practical BFN's. Both inner and outer conductors have rectangular shape. The inner conductor is located halfway between the top and bottom walls, but in some parts of the network it may be offset with respect to the side walls (Fig. 1b). In some cases coupled lines are realized, as in Fig. 1c.

The first step in the modeling of RCC circuits is of course the analysis of the uniform transmission lines of Fig. 1. The knowledge of the modal spectrum is required not only for determining the frequency range of single mode propagation, but also for implementing the subsequent modal analysis, or mode-matching (MM) technique [3], of the discontinuities. The generalized transverse resonance concept can be used to this purpose.

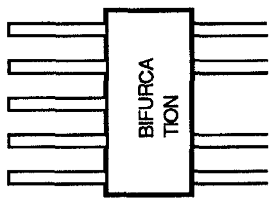

Fig. 2. Equivalent transverse circuit of the RCC

Looking into the transverse direction, the cross-section of a RCC can be seen as a bifurcation problem in a parallel plate waveguide (PPW). Using modal analysis, a generalized multiport network can be used to model the bifurcation. Fig. 2 shows the generalized equivalent transverse circuit of the RCC. The ports on the left hand side represent the modes of the PPW, shorted to the outer conductor of the cable. The ports on the right hand side represent the modes of the bifurcated section, open circuited to the plane of symmetry (magnetic wall). The resonance condition of Fig. 2 leads to the characteristic equation of the structure. From that, the modal spectrum of the cable can be computed.

3. MODELING OF DISCONTINUITIES

Once the modal spectra of the transmission lines have been computed, step discontinuities, such as that depicted in Fig. 3a can be analyzed using modal analysis. The EM field is expressed at the two sides of the discontinuity in terms of normal modes of the respective transmission line. Imposing the boundary conditions at the plane of the discontinuity one obtains a linear system of equations in the expansion coefficients. From this, the characterization of the discontinuity is obtained using known techniques.

The analysis of a junction, see Fig. 3b, is a much more difficult task. This is in fact a multiaxial discontinuity, i.e. a 3-D boundary value problem.

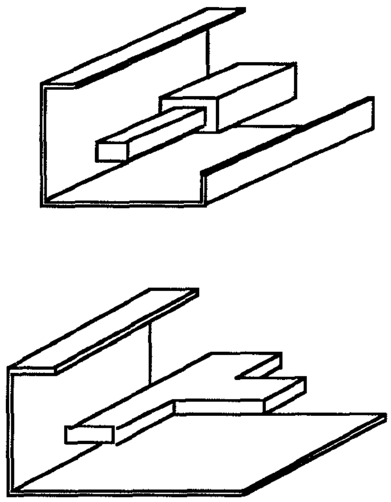

Fig. 3. Step discontinuity and T-junction in RCC

To solve this problem, a 3-D field-matching technique has been developed, which is an extension to the 3-D case of the transverse resonance analysis adopted for finline (quasi-planar) discontinuities [4]. We first create a resonant cavity by adding shorting planes some distance away from the discontinuity. These planes are located far enough so as not to perturb the reactive fields in the proximity of the discontinuity. The cavity is then subdivided into parallelepipedal elements, where the EM field is expanded in terms of resonant modes [5]. At the interfaces between volume elements the tangential fields are expanded in terms of a suitable set of 2-D basis functions. Again, the continuity conditions at the interfaces lead to a homogeneous system of equations in the expansion coefficients. The parameters of the discontinuity are computed after performing numerically some resonant experiments with different locations of the shorting planes. The number of resonant experiments can be made equal to the number of ports of the discontinuity [6]. In general this procedure is rather computer intensive.

Simplified computational algorithms can be set up in cases when the thickness of the central conductor is constant. This is the case of Fig. 3b. The structure can be divided into layers in such a way that all interfaces between adjacent 3-D elements are parallel. In this manner one obtains a field formulation equivalent to the generalized transverse resonance technique [6]. Replacing the symmetry plane with a magnetic conductor, it is easily seen that the T-junction of Fig. 3b, shorted at the three ports, consists of 4 parallelepipedal elements. Each element is modeled as a generalized multiport. The equivalent circuit of the resonant cavity containing the T-junction consists therefore of 4 multiports connected as in Fig. 4. Compared to conventional MM technique, the computation of the modal spectrum of the lines connected at the junction is avoided, leading to a considerable simplification of the problem. In spite of the complexity of the boundary value problems involved, the computer analysis can be performed on a PC. The computation of the scattering parameters of a symmetrical T-junction requires typically 5 to 10 minutes on an IBM AT.

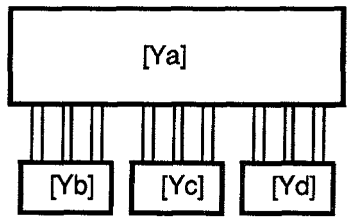

Fig. 4. Generalized equivalent circuit for application of the generalized transverse resonance method to the T-junction

4. THEORETICAL AND EXPERIMENTAL RESULTS

The theoretical models described in the previous section have been verified on several test samples. Some examples are given here.

Fig. 5 shows the theoretical and experimental scattering parameters of a 25 ohm section of RCC inserted between two 50 ohm sections. The outer conductor has dimensions 11x10 mm. The 25 ohm inner conductor has sides 7x6 mm while the 50 ohm has 4.16x4.16 mm. The 25 ohm section is 20 mm long. The frequency range is 2-6 GHz. For the experiments it was necessary to realize transitions from RCC to SMA connectors. The transitions had been already optimized experimentally for the measurement of the T-junction (see below) to have reflection loss better than -30 dB in the whole band. The transitions however were not included in the theoretical simulations of Fig. 5. A fairly good agreement between theory and experiment is observed. Some problems in the experimental equipment or in the realization of the transitions may have produced a slight discrepancy, particularly at higher frequencies.

A comparison between theoretical and experimental results on a symmetrical T-junction is shown in Fig. 6. The junction is made of three 50 ohm RCC's. The scattering parameters of the junction were measured on a HP 8510B ANA up to 6 GHz. This was the limit frequency before the onset of higher order modes in the RCC. The agreement between theory and experiment shown in Fig. 6 is quite satisfactory. A small discrepancy is observed in the higher frequency range. This may be ascribed either to a reduced numerical accuracy as the cutoff frequency of higher order modes is approached or to inaccuracy of the experiment. In any case, the maximum error in the transmission parameter is 0.3 dB. The transitions to SMA were modeled as small shunt capacitors and included in the theoretical simulations of Fig. 6. The capacitance value of the transition was determined experimentally by measuring a 50 ohm sample of RCC.

The realization of branch-line couplers involves several cascaded non-symmetrical T-junctions. In order to measure a non-symmetrical junction, a test sample was manufactured consisting of two T's cascaded in reversed position. The third port of each T was shorted to the outer conductor. A symmetrical two-port structure with 50 ohm at both sides was formed in this manner. (This structure is actually the odd-mode configuration of a 2-branch coupler.) The scattering parameters were measured and compared with the theoretical predictions with excellent agreement, as demonstrated in Fig. 7. Again, the transitions have been included in the theoretical simulations.

5. CONCLUSIONS

Discontinuities in rectangular coaxial cable have been evaluated both theoretically and experimentally. A 3D field-matching technique has been developed for the analysis of multiaxial discontinuities. In spite of the complexity of the boundary value problems involved, the computer analysis is performed on a PC. Measurements were in very good agreement with theoretical predictions.

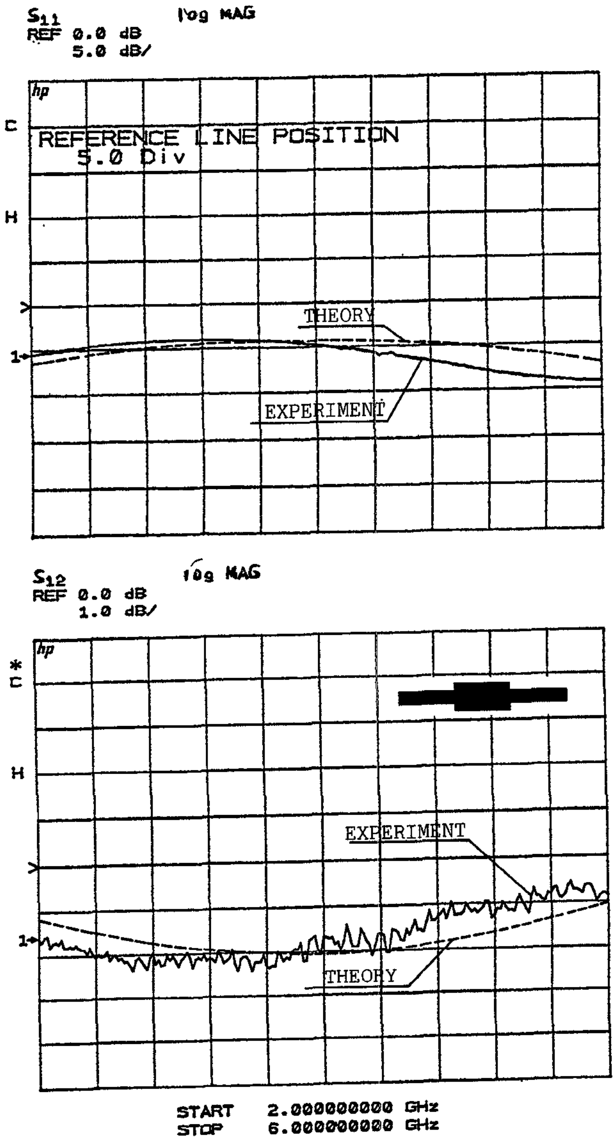

Fig. 5. Scattering parameters of cascaded step discontinuities

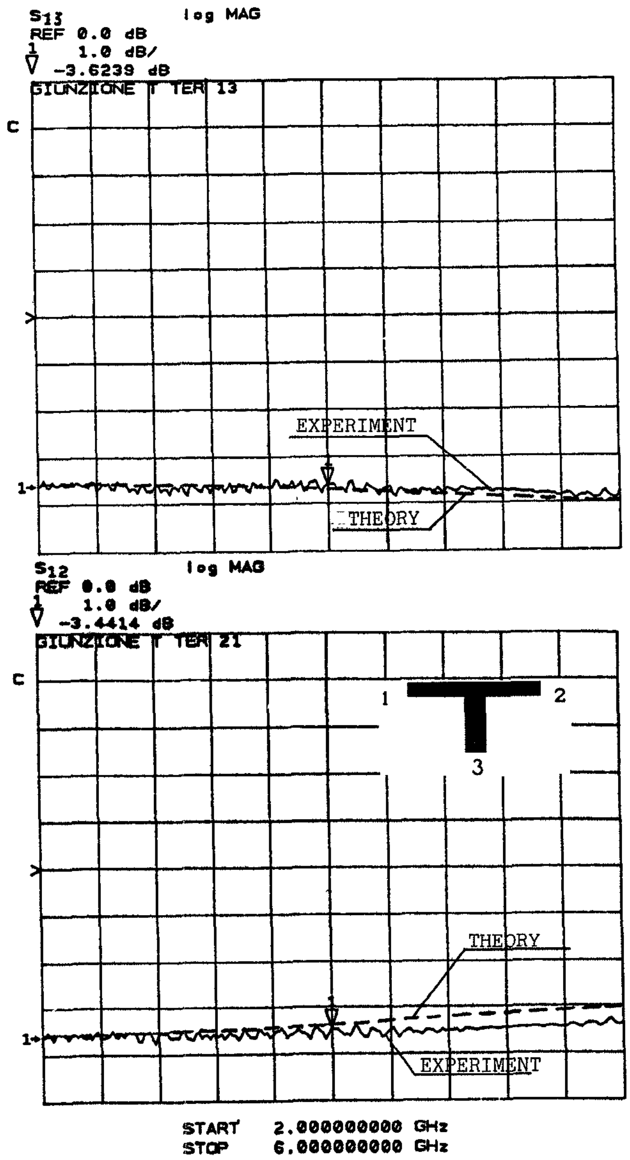

Fig. 6 a,b. Translmission parameters of a symmetrical T-junction

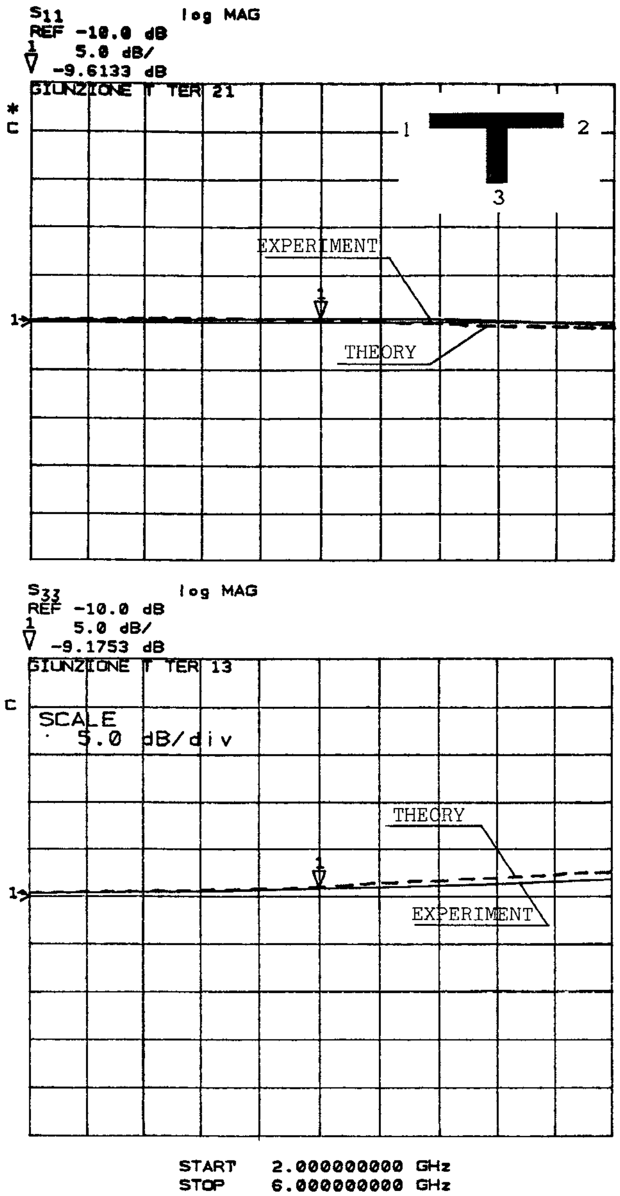

Fig. 6 c, d. Reflection parameters of a symmetrical T-junction

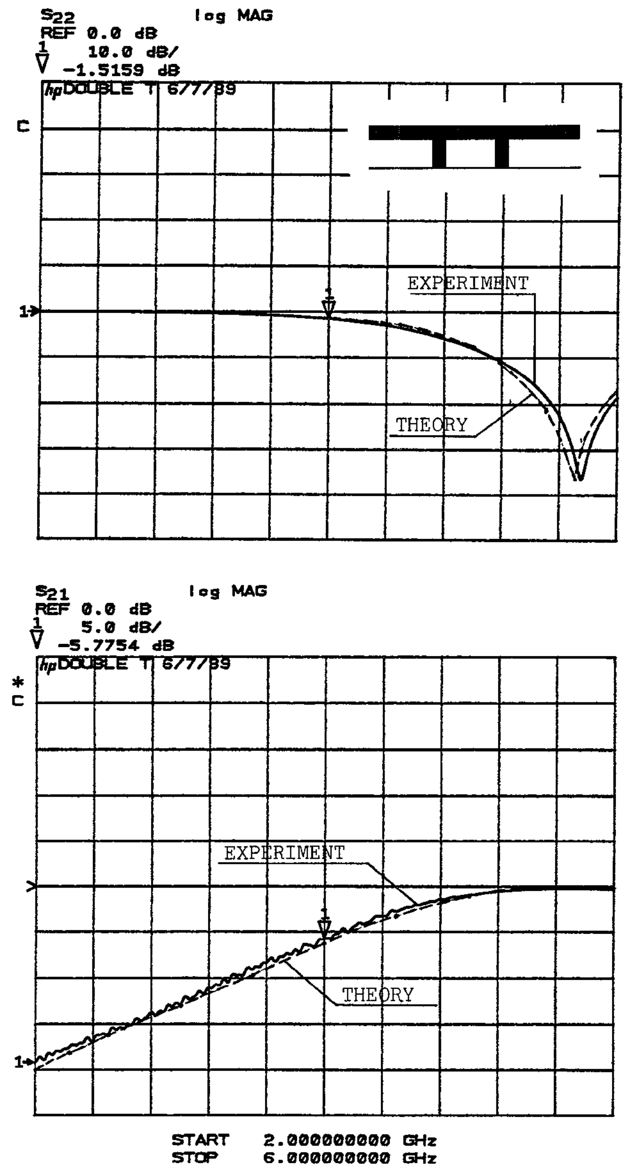

Fig. 7. Scattering parameters of non-symmetrical cascaded T-junctions

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