ANALYSIS OF MICROSTRIP T-JUNCTION AND ITS APPLICATION TO THE DESIGN OF TRANSFER SWITCHES

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Abstract

A simplified field theory formulation is presented for analysing microstrip T-junctions. The computed junction scattering parameters (magnitude and phase) are in good agreement with experimental results. The formulation is extended to analyse a microwave transfer switch realized by cascading a number of microstrip T-junctions.

Introduction

Using the mode matching technique this paper presents a simplified formulation for analyzing microstrip T-junctions. In contrast to the approaches reported in [1]-[4] which yield only the scattering *parameters of the dominant mode*, the formulation presented in this paper provides the scattering parameters of the dominant as well as the higher order modes. This formulation promises to be useful in characterizing microstrip circuit elements printed on a high dielectric constant substrate where the effect of the higher order modes interaction has to be taken into account. To verify the validity of the formulation we compare our computed results with experimental results. A good agreement is observed with measured data for a single and cascaded T-junctions.

We also consider in this paper the analysis and design of transfer switches. Microwave transfer switches are four port devices widely used in many applications to switch to back-up equipment in the event of any failure within the primary systems [5]. They have been also frequently used in the design of switched filter banks. A computer aided design algorithm has been developed to design transfer switches realized by cascading a number of microstrip T-junctions. Numerical results are presented for a transfer switch designed at 5 GHz.

Formulation

Let the microstrip T-junction shown in Figure 1 be divided into four regions. The fields in region I, II and III can be expanded in terms of the planar waveguide modes derived in [3]. The fields in region IV can be written in terms of three standing wave solutions as follows:

$$E_{1v} = \sum C_{1n}\, \phi_{1n} + \sum C_{2n}\, \phi_{2n} + \sum C_{3n}\, \phi_{3n} \tag{1}$$

$$H_{1v} = \sum C_{1n}\, \psi_{1n} + \sum C_{2n}\, \psi_{2n} + \sum C_{3n}\, \psi_{3n} \tag{2}$$

The standing wave solution ϕ_1 and Ψ_1 are derived by inserting magnetic walls at the cross sections planes S_2 and S_3 defined in Figure 1. The remaining standing wave solutions ϕ_2, ϕ_3, Ψ_2 and Ψ_3 are derived in a similar way. By matching the electric and magnetic fields at the junction cross sections, the incident and reflected amplitude vectors A_i and B_i of the three ports can be related as:

$$\begin{bmatrix} A_I + B_I \\ A_{II} + B_{II} \\ A_{III} + B_{III} \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} A_I - B_I \\ A_{II} - B_{II} \\ A_{III} - B_{III} \end{bmatrix} = \begin{bmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_3 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \tag{4}$$

where H_{ij} and M_i are respectively the E-field and the H-field mode matching matrices. In equations (3) and (4) the only nondiagonal matrices are H_{13}, H_{31}, H_{23} and H_{32}.

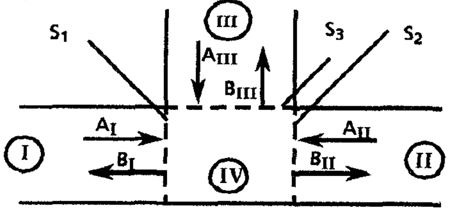

Figure 1 Microstrip T-junction

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After some manipulations the scattering parameters of the microstrip junction can be written as:

$$[S] = [I] - 2.0 \begin{bmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ o & 0 & M_3 \end{bmatrix} x \begin{bmatrix} (M_1+H_{11}) & H_{12} & H_{13} \\ H_{21} & (M_2+H_{22}) & H_{23} \\ H_{31} & H_{32} & (M_3+H_{33}) \end{bmatrix}^{-1} \qquad (5)$$

The computational efficiency and simplicity of this formulation is evidenced by the fact that most of the above matrices are diagonal and by the ability to express the junction scattering parameters for the dominant as well as the higher order modes by a single matrix equation.

Numerical and Experimental Results

To check the validity of the formulation we compare in Figure 2 our scattering parameters results with the experimental results given in [4] for a single T-junction. We also compare in Figure 3 the computed results with experimental results for a microstrip circuit constructed by cascading a number of T-junctions. The results given in Figures 2 and 3 were computed using 30 expansion terms in region IV and 10 modes in each of the three regions I, II and III. It is noted that the computed results are in good agreement with the measurement data.

In Figure 3, the short circuited was realized using edge plating. The same circuit was constructed using PIN diodes to realize the three short circuited ends. The performance achieved is given in Figure 4. The circuit acts as a simple SPST switch having an insertion loss of 0.7 dB and a rejection of 30 dB over 1 GHz bandwidth. A better isolation over a larger bandwidth can be achieved by reoptimizing the circuit dimensions to compensate for the PIN diode reactances.

Analysis of Transfer Switches

The transfer switch considered in this paper is shown in Figure 5. It is a four port device constructed by cascading a number of T-junctions. The two states of this switch are described in Table 1.

Due to symmetry we only need to analyze one quarter of the structure with electric and magnetic walls along the planes of symmetry AA' and BB' as shown in Figure 6. The reduced structure consists of three cascaded T-junctions and two diodes. For accurate characterization of the switch performance the equivalent circuit of the PIN diode has to be taken into account during the optimization process of the circuit dimensions. In this analysis, the on and off states of the diodes are replaced by short and open circuit respectively. With the use of the formulation presented in this paper and the generalized scattering matrix technique given in [6], the input scattering matrix of the reduced structure can be evaluated. The overall scattering matrix of the four-port transfer switch can then be written as:

$$S_{11} = \frac{1}{4}[\, S_{mm} + S_{em} + S_{me} + S_{ee} \,] \qquad (6)$$

$$S_{12} = \frac{1}{4}[\, S_{mm} - S_{em} + S_{me} - S_{ee} \,] \qquad (7)$$

$$S_{13} = \frac{1}{4}[\, S_{mm} - S_{em} - S_{me} + S_{ee} \,] \qquad (8)$$

$$S_{14} = \frac{1}{4}[\, S_{mm} + S_{em} - S_{me} - S_{ee} \,] \qquad (9)$$

where S_{mm}, S_{me}, S_{em}, and S_{ee} are the scattering matrices seen at the input port of the reduced structure given in Figure 6 with electric and magnetic walls placed at cross section planes AA', and BB'. The remaining scattering matrices of the transfer switch can be readily deduced on the basis of symmetry relations.

A computer aided design algorithm is developed by combining the analysis given in this paper with an optimization program based on the minimax approach [7]. In the algorithm, the circuit parameters of the reduced structure shown in Figure 6 are varied until the desired scattering parameters are achieved over a number of frequency sampling points. Figure 7 shows the computed results of a switch designed at 5 GHz. The switch dimensions are optimized to provide 30 dB rejection over a bandwidth of 500 MHz.

Conclusion

This paper has presented a simple and numerically efficient formulation for the characterization of microstrip T-junctions. The use of the formulation in the design of microwave transfer switches has been demonstrated. The numerical results obtained for the scattering parameters of a single and cascaded T-junctions agree well with the experimental data.

References

[1] I. Wolff G. Kompa and R. Mehran, "Calculation method of microstrip discontinuities and T-Junctions", Electron Lett', vol. 8 pp. 177-179, 1972.

[2] E. Kuhn, "A mode Matching Method for Solving Field Problems in Waveguides and Resonator Circuits", AEU, vol. 27, pp. 511-518, Dec. 1973.

[3] I. Wolff, "The Waveguide Model for the Analysis of Microstrip Discontinuities", in T. Itoh, Ed. Numerical Techniques for Microwave and Millimeter Wave Passive Structures, John Wiley, New York, pp. 445-495, 1988.

[4] I. Wolff, "From Static approximations to full-wave analysis: The analysis of a Planar line discontinuities", Int. Journal of Microwave and Millimeter wave Computer-aided Engineering, vol. 1, no. 2 pp. 117-142, 1991

[5] N. Whittaker et al., "A Novel RF Switch for High Power Space Applications", Microwave J. pp. 127-129, October 1990.

[6] R.R. Mansour and R.H. MacPhie, "An Improved Transmission Matrix Formulation of Cascaded Discontinuities and and its Application to E-Plane Circuits", IEEE Trans. Microwave Theory and Tech. vol. MTT-34, pp. 1490-1498, Dec. 1986

[7] J.W. Bandler et al., "Large Scale Minimax Optimization of microwave Multiplexers", In Proc, European Microwave Conf. Dublin, Ireland, pp. 435-440, 1986.

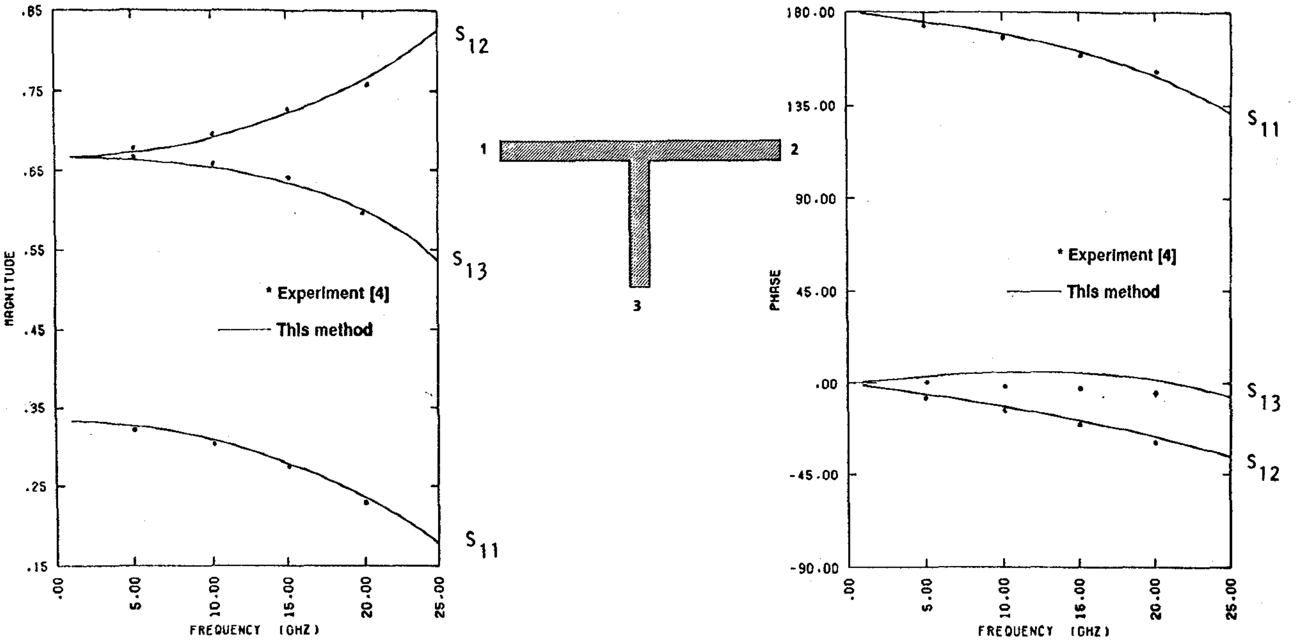


Figure 2. Comparison between theoretical and experimental results. ε_r = 9.87, H = 0.635 mm, W = 1.27 mm

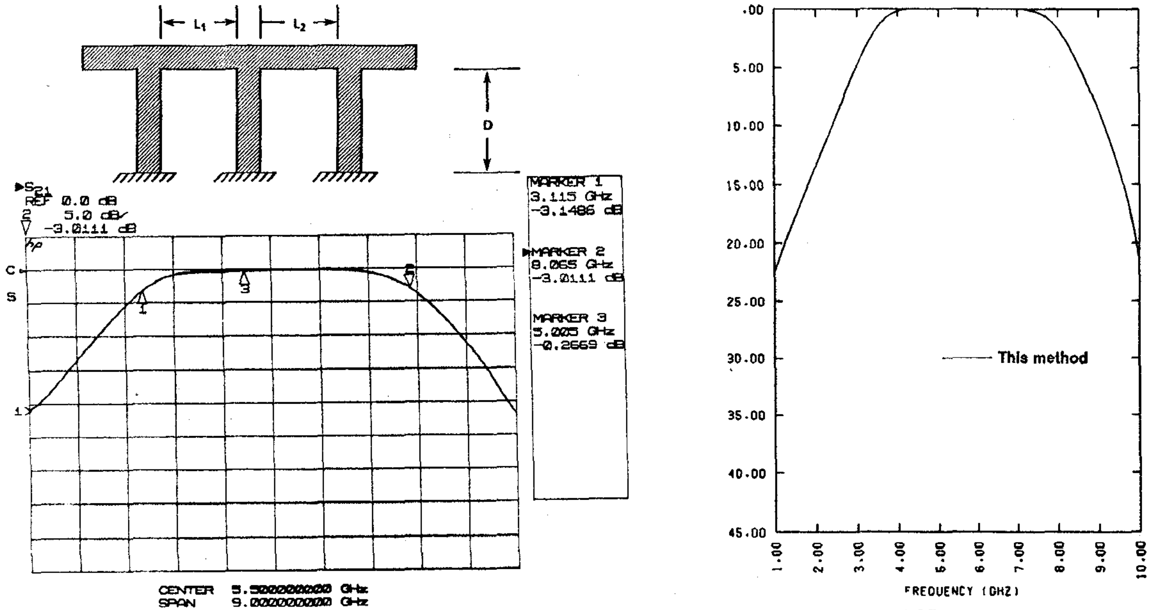
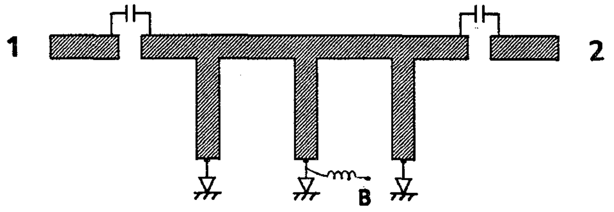


Figure 3. Comparison between theoretical and experimental results. ε_r = 10.0, $H = 1.27 mm$, $W = 1.2446 mm$, L_1 = 4.1402 mm, L_2 = 4.1402 mm, D = 5.5372 mm



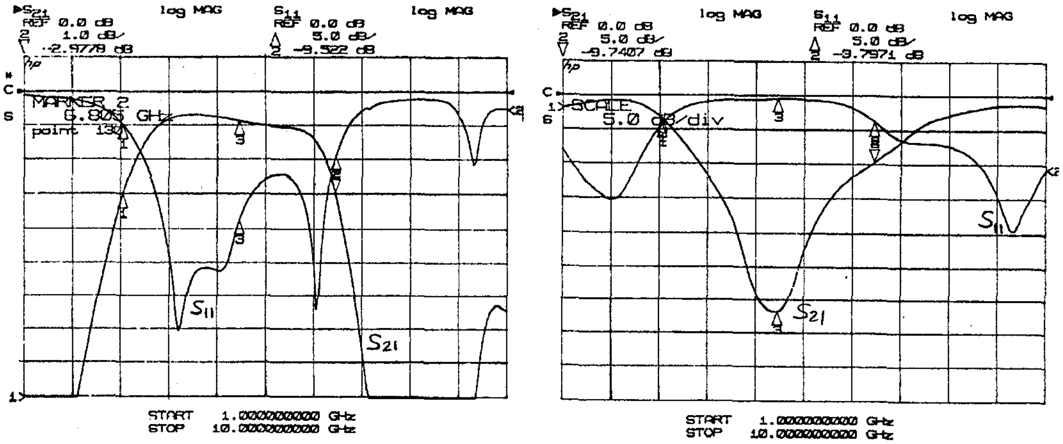


Figure 4. Measured Performance of a SPST switch. Dimensions are as shown in Figure 3. a) ON state b) OFF State

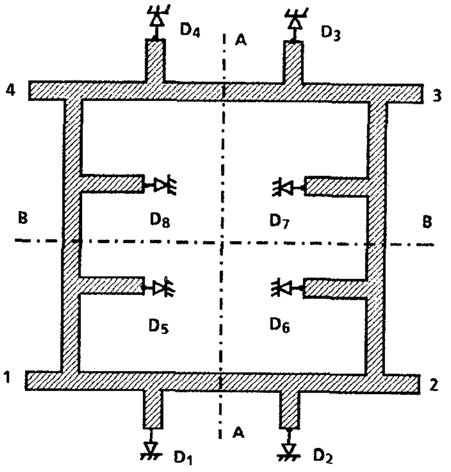


Figure 5. A Microwave Transfer Switch

Table 1: Description of the Two States of the Transfer Switch

State	Diodes	Insertion Loss Port Pairs	Isolation Port Pairs
1	D_1, D_2, D_3, D_4 (ON)	1 - 2	1 - 4
	D_5, D_6, D_7, D_8 (OFF)	3 - 4	2 - 3
2	D_1, D_2, D_3, D_4 (OFF	1 - 4	1 - 2
	D_5, D_6, D_7, D_8 (ON)	2 - 3	3 - 4

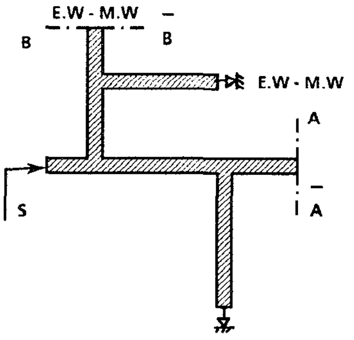


Figure 6. Reduced Structure

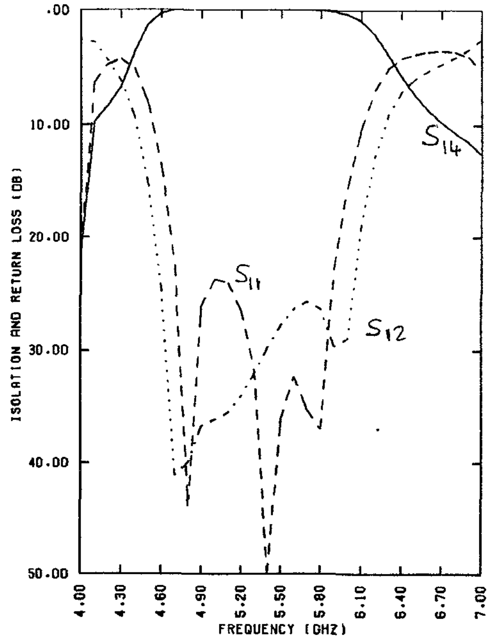


Figure 7. The computed results of the transfer switch shown in Figure 5 for state 2.