Rigorous Analysis of Compensated E-plane Junctions in Rectangular Waveguide

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Abstract

A rigorous full wave analysis of compensated E-plane junctions has been developed using a segmentation technique associated with an admittance matrix representation. The structures are divided into rectangular and right-angled isosceles triangular regions for which the admittance matrix is expressed in closed form. The properties of compensated T-junctions, bifurcations and stubs are investigated showing significant improvements of the electrical performances over the uncompensated counterpart. The computer analysis of any structure requires less than one second per frequency point on 486-50 MHz IBM compatible personal computer.

Introduction

The electrical performance of waveguide components is affected by discontinuity effects. Higher order modes excited at the discontinuities and junctions alter the electrical behavior of a waveguide circuit with respect to its transmission line counterpart. To alleviate such unwanted effects, it is common practice to modify the geometry of junctions and discontinuities by the introduction of suitable compensating elements [1]. At the same time, however, the complication in the structure geometry is such that a rigorous analysis is usually extremely difficult or even impossible. As a consequence, the design of compensated discontinuities essentially relies on expensive experimental work on the test bench.

A possible alternative is the use of numerically oriented methods, such as Finite Difference or Finite Element methods, that offer sufficient flexibility to analyze complicated and irregular geometries. The drawback is the lower numerical efficiency with respect to analytically oriented methods, such as Mode Matching method or Spectral Domain approach. In particular, numerical optimization, that requires hundreds or thousands analyses, becomes easily unaffordable in the lack of an analytical model.

In this paper, a rigorous analytical approach is employed to analyze waveguide discontinuities compensated by the introduction of right-angled isosceles triangles. The method is based on the segmentation of the geometry into rectangular and triangular cells. Both are characterized in terms of the generalized admittance matrix, expressed in closed form. The analysis is then obtained by solving the resultant equivalent circuit. The use or triangles in addition to rectangles makes it possible to analyze a much wider class of structures than usually possible with conventional mode matching techniques. Thanks to the analytical approach, the numerical efficiency is very high. Fig.1 shows a number of discontinuities that can be analyzed by the present technique.

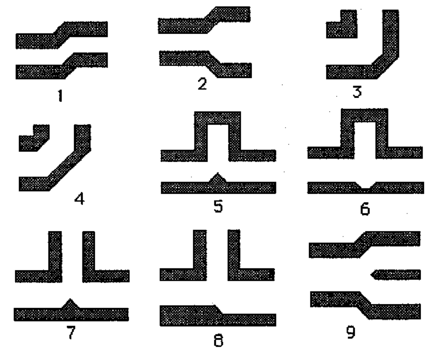

Fig. 1. E-plane discontinuities that can be analyzed by the present method

Method of Analysis

The analysis of waveguide discontinuities by the generalized admittance matrix has been described in [2, 3]. The method consists of dividing the structure into several simple regions (cells) where the modes, thus the associates Green's function, are known. In the admittance formulation we choose as unknowns the tangential components of the electric field at the interface between different regions. The magnetic field in the various cells is then readily obtained in terms of a modal expansion. The continuity of the tangential components of the magnetic field at the interfaces between the different cells provides a set of functional equations that, after Galerkin discretization yields the desired solution. After the discretization process, each region is described by a generalised admittance matrix. The number of basis functions used to represent the tangential components of the electric and magnetic field corresponds to the number of electrical ports present in the network. The field solution for the microwave structure is then reduced to the solution of its generalized equivalent circuit.

For E-plane discontinuities, the generalized admittance matrix can be expressed in closed form both for a rectangular cell and, as has recently been shown [4], for a triangular one. As a consequence, the analysis of the structure requires a very short CPU time on a personal computer.

As an example, Fig. 2a shows the segmentation of a compensated T-junction, while the equivalent circuit is shown in Fig. 2b. The total number of ports of this network is typically less then one hundred. A complete analysis of a compensated T-junction, for instance, takes less than 1 s per frequency point on a 486-50 MHz IBM compatible PC.

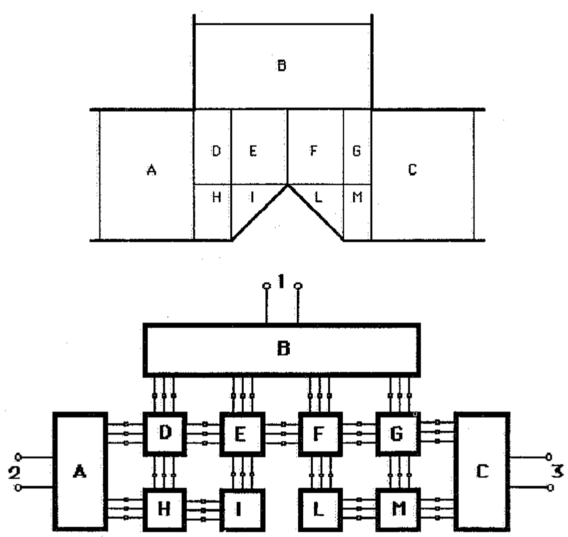

Fig.2 Segmentation of a compensated T-junction and its equivalent circuit

T-Junctions

To compensate a T-junction between two rectangular waveguides, a triangular wedge can be used as shown in Fig.1. The width of the wedge can be varied to optimize the performance of the junction.

Fig. 3 shows the dimensions of the conventional and compensated T-junctions used in our analysis. The dimensions are chosen so that waveguide 2 and 3 have half the characteristic impedance of waveguide 1 (WR75). The computed behaviors of the T-junctions are compared in Fig. 4a, b for different values of the wedge width 2d.

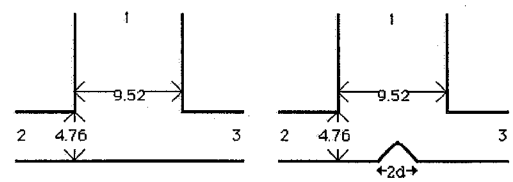

Fig. 3. Non compensated and compensated T-junctions. Dimensions are in mm.

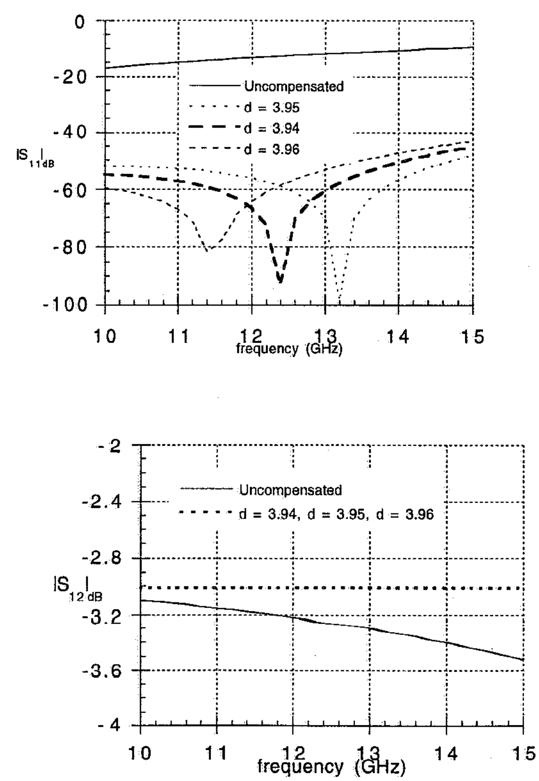

Fig.3 Scattering parameters S_{11} and S_{21} of compensated and non compensated T-junctions

The presence of the wedge is seen to yield a substantial improvement in the return loss of the junction seen from port 1, as it reduces s_{11} from more than -18 dB to less than -42 dB in the whole band 10-15 GHz. A perfect matching is obtained at a frequency that depends of the wedge width. The effect of the wedge improves also the transmission from port 1 to port 2 and makes s_{21} frequency independent.

Bifurcations

Bifurcations (and n-furcations) are typically used in the realization of E-plane diplexers (and multiplexers). One way to compensate such junctions is to design a stepped transition between the input and output waveguides [5]. The use of triangular elements allows us to design smooth rather then stepped transitions. Fig. 4a shows the geometry of an uncompensated bifurcation in the E-plane of a rectangular waveguide. Two different ways to compensate a waveguide bifurcation have been investigated. In Fig. 4b a triangular taper is introduced to shape the wall separating the two waveguides. In Fig. 4c also the input waveguide has been tapered. Observe that, in contrast to Fig. 3, all waveguides are standard WR75 and have the same impedance.

The scattering parameters s_{11} and s_{21} of the three bifurcations of Fig. 4 are plotted in Fig. 5 a,b. As a reference, the corresponding scattering parameters of an ideal bifurcation with no discontinuity effects are also plotted. The bifurcation B3 gives the best results in terms of return loss from port 1, which is better than the ideal case. The response of B2, on the contrary, does not show any significant improvement over the uncompensated bifurcation B1.

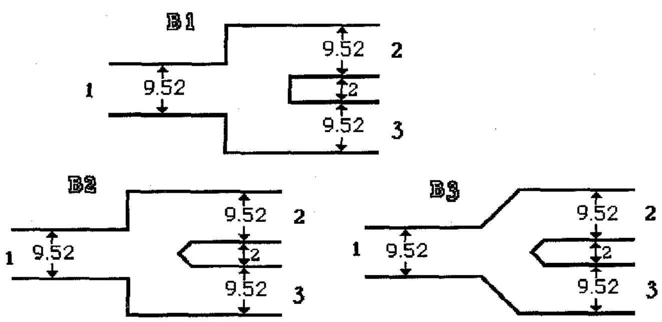

Fig 4. Uncompensated and compensated bifurcations. Dimensions are in mm.

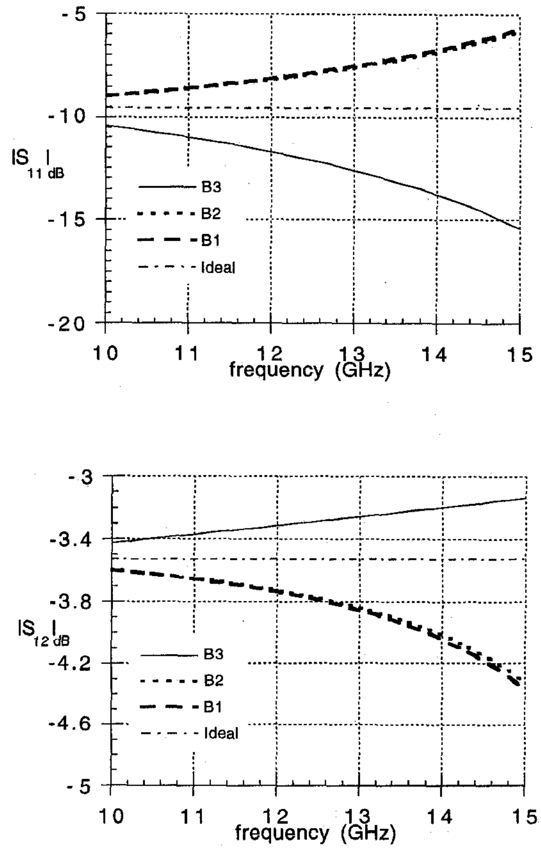

Fig.5 Scattering parameters of the bifurcations of Fig. 4

E-plane stubs

As a final example, we consider here two different possible compensations of waveguide stubs using triangular elements (Fig. 6).

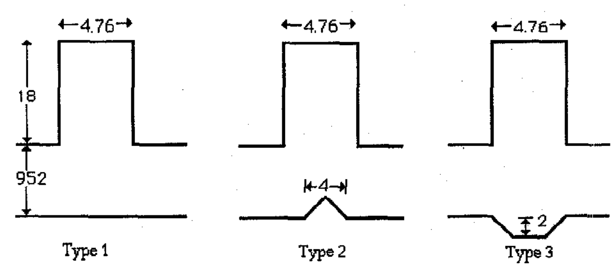

Fig. 6 Uncompensated and compensated waveguide stubs. Dimensions are in mm.

The computed return loss of the three stubs of Fig. 6 are shown in Fig. 7. The frequency of the reflection zero is seen to be affected by the compensation, while the transmission zero is about the same for all stubs. Such a modification in the stub geometry introduces an additional degree of freedom and can be usefully employed to improve the performace of a number of waveguide components (filters, etc.).

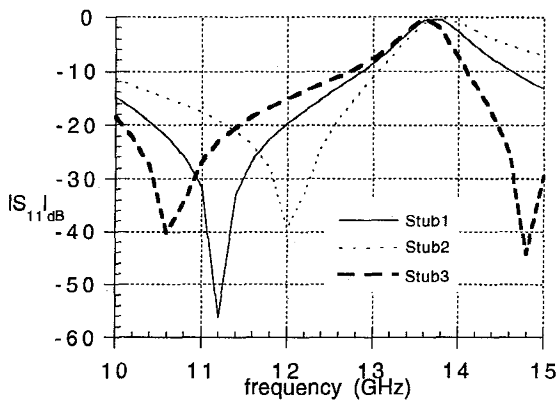

Fig.7 Return loss of the stubs of Fig. 6

Conclusions

A rigorous and efficient analysis method of compensated waveguide junctions has been developed. The method employs a segmentation into rectangular and righ-angled isosceles elements. It allows one to design new classes of components avoiding the use of more computer intensive numerical techniques.

References

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