Electromagnetic Simulation of Microstrip Structures with Symmetrically Coupled Microstrip Ports

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Abstract

An electromagnetic simulation, based on a triangular grid and a rectangular grid, is applied to the analysis of coupled microstrip structures, and a standing wave detection algorithm is developed for the S-parameter extraction of symmetrically coupled microstrip lines. The process extracts the ratios of the reflected waves over the incident waves and the propagation constants of the two modes (even and odd) from the numerically solved electric current standing wave distributions. Presented in this paper is a full-wave analysis of coupled microstrip structures and a de-embedding technique that solve for the propagation constants and S-parameters based on the guided wave modes of the feed structures. The technique can also be applied to other symmetrically coupled structures.

Introduction

An electromagnetic simulation algorithm has been developed for the analysis of planar microstrip structures of arbitrary shape [1]-[3]. The approach basically divides an arbitrarily shaped microstrip structure into a combination of triangular cells and rectangular cells, and solves the current distribution on the microstrip represented as the roof-top functions on the cells. Several de-embedding techniques have been developed to extract the S-parameters and the propagation constant of single microstrip lines. However, these techniques fail for structures with ports located in regions with coupled microstrip lines, as shown in Figure 1.

Many other full-wave algorithms do not address the coupled line de-embedding issues for the case when ports are in close proximity to one another [4]-[6]. One de-embedding scheme for coupled microstrip lines was presented, where an error network was introduced to remove the source discontinuities [7]. Such an approach requires calculation of the error network parameters before the de-embedding of a discontinuity, thus increasing the simulation time. Furthermore, the de-embedded result of an error network technique is application-specific, preventing further translation of the measurement plane based on the characteristics of the guided wave structure. In other words, the reference planes of the resulting S-parameter model are fixed.

For symmetric coupled lines, the guided wave modes can be described by a decomposition into even and odd mode characteristics (see Figure 1). By defining the ports based on the propagation modes, the reference planes can be shifted quite easily. As a final step, this mode-based S-parameter model is transformed into an S-parameter model that is normalized to 50 ohms. This final transformation is required to compare the results to measured data or simulations based on a 50-ohm system.

Theory

In this technique, the current distributions on two parallel strips of a microstrip structure are detected and separated into the incident waves and reflected waves of even and odd modes. The propagation constants of the two modes are evaluated from the extracted incident and reflected waves. The propagation constants of the feed structures and the S-parameters of the circuit under test are obtained with this procedure. For this coupled port, the resulting S-parameter model is normalized to the impedance of the mode, odd or even. By using this form of the S-parameters, electrical models with different reference planes can be obtained easily without any additional electromagnetic simulations.

The 50-ohm S-parameters can be obtained from this mode-based S-parameter model (when a *pair* of coupled microstrip ports are considered as two single ports) once the currents and voltages are known on the structure through renormalization.

Results

Any microstrip circuit with single strip ports and symmetrically coupled ports can be analyzed with the full-wave solutions of the electric current distributions and the de-embedding scheme introduced in this paper. As an example, Figure 2 shows the S-parameters of the coupled line structure shown in Figure 1. The even mode and odd mode of the coupled line port are referred to as port 3 and port 4, respectively. As expected, the |S31| and |S41| are kept at around -3.05 dB in the whole frequency range. One validation experiment is for self-consistency. We compared the numerical results, which were obtained in two different ways, for the directional coupler. One simulation was formed by connecting the two identical structures of Figure 1 back-to-back, where ports in the midpoint of the coupler are identified by the even and odd mode of the structure. The other simulation treats the entire directional coupler in a single simulation. The entire directional coupler structure and the comparison are shown in Figure 3 and Figure 4, respectively. The results obtained using the two different methods agree perfectly, showing that the mode-based port definition is consistent with a terminal-based definition.

A second validation exercise compares the model generated by the electromagnetic simulation to analytical models that are generally accepted by the industry. A comparison of this type is shown in Figure 5. Note that the two graphs are nearly identical.

Conclusions

A technique has been presented that calculates the guided wave characteristics, a mode-based S-parameter model, and a node-based 50-ohm model for structures, where the ports are associated with single or symmetrically coupled lines. The intermediate mode-based S-parameter model enables an easy translation of the measurement plane to alternate locations and the 50-ohm S-parameters are required for comparison purposes. The technique has been shown to be self-consistent as well as consistent with industry-accepted analytical models.

References

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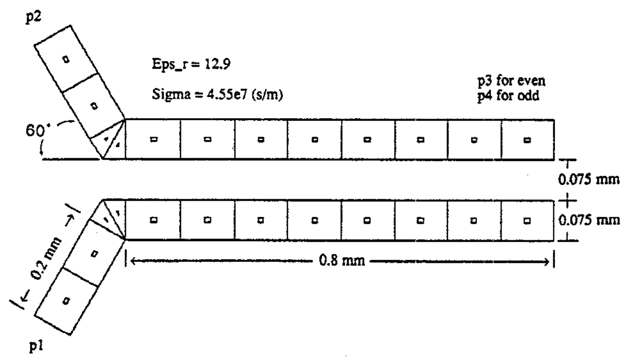

Figure 1. A Coupled Line Structure

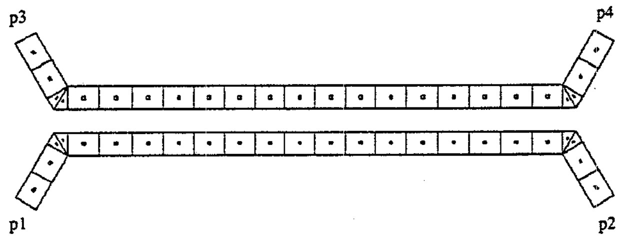

Figure 3. A Directional Coupler Formed by the Two Coupled Line Structures Shown in Figure 1

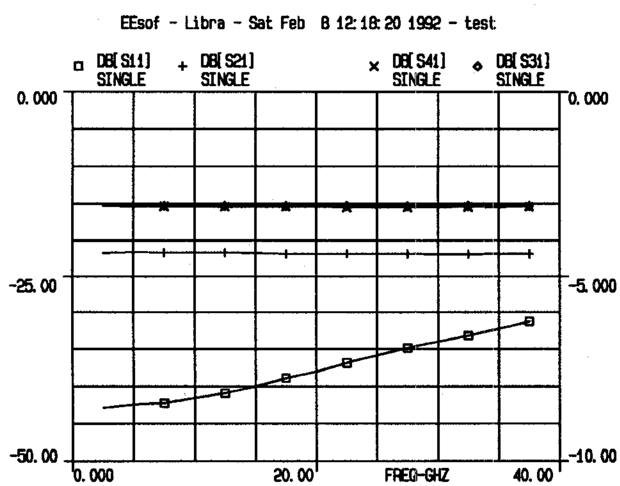

Figure 2. S-parameters of the Coupled Line Structure

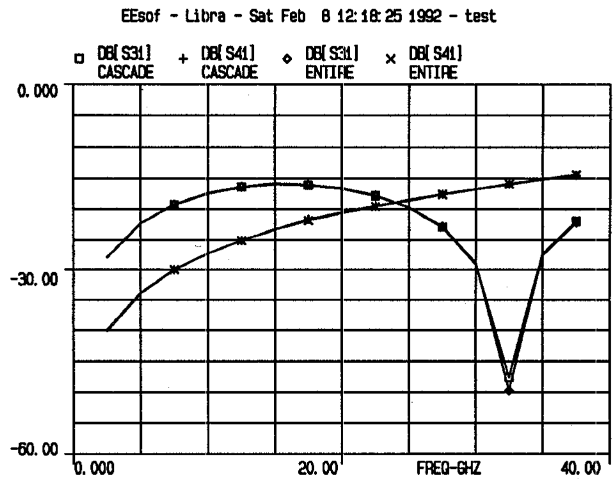

Figure 4. S-parameters of the Directional Coupler

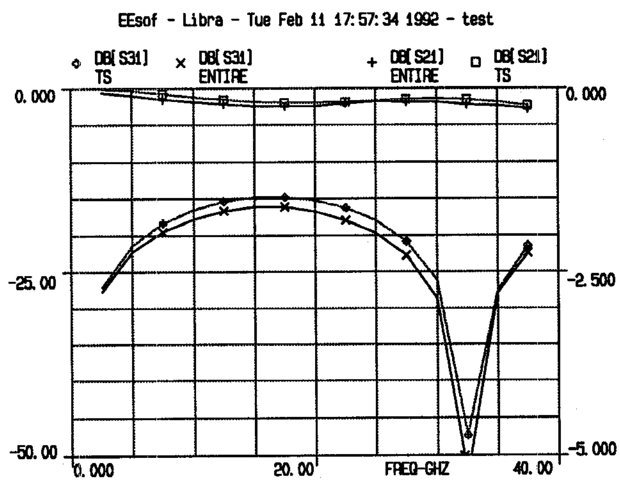

Figure 5. Comparison of Electromagnetic Simulation Model to Analytical Model