Analysis of multilayer circuits by an efficient iterative technique

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Abstract — An efficient iterative technique based on the wave concept for designing multilayer planar circuits is presented. It provides a mixed resolution in modal and spatial domain taking the best advantage of each resolution domain with lower computation time. In this sense, a program in MATLAB has been elaborated to validate this approach. The numerical results are compared with those in the available literature.

I. Introduction

For the electromagnetic community, wave propagation in multilayer structures is an important and interesting subject [1]. RF and microwave circuits are usually fabricated in single layer configuration although multilayer circuit structures have been widely used for digital and low frequency systems. The use of multilayer planar circuits makes microwaves circuits more compact and the design more flexible [2-3]. This article presents an efficient technique based on the Wave Concept Iterative Procedure (WCIP) for solving continuity conditions in terms of waves rather than in terms of tangential electric and magnetic fields to analyze multilayer structures. This method is not conditioned by the complexity of the circuit design and was proved to be particularly interesting for planar circuits [4]. The WCIP approach consists in separating the structure under study into interfaces with upper and lower homogeneous media. The boundary conditions on the interfaces are represented by a diffraction operator, S, defined in the spatial domain. In the homogeneous media, the wave propagations between interfaces are represented by a transfer matrix, T, and on the extremities of the circuit (top and bottom) by a reflection operator, Γ, both defined in the modal domain. In the work reported herein, analysis and simulation of a slot coupled patch antenna were carried out. Section 2 provides the theoretical formulation used with the WCIP. Simulations and results are presented in section 3. Finally, conclusions are included in section 4.

II. Formulation of the WCIP

The representation of electromagnetic fields using the Wave Concept is a well-established procedure [5]. It is introduced to express the boundary conditions on the interface air/dielectric in terms of waves. The spatial and modal waves are directly deduced from each other with a Fast Modal Transformation (FMT) and its inverse transform (FMT^{-1}). Let us consider a single, but general, interface problem with its waveguide transversal cut shown on Fig. 1.

The source A_{0i} generates two waves, one on each side of the interface Ω_i.

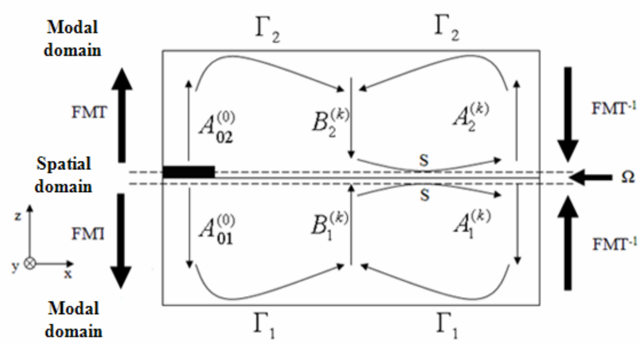

Fig. 1. ***A*** and ***B*** waves behavior and domains transform in the Iterative process for a single layer

This wave concept is extended for multilayer structures as shown in Fig. 2.

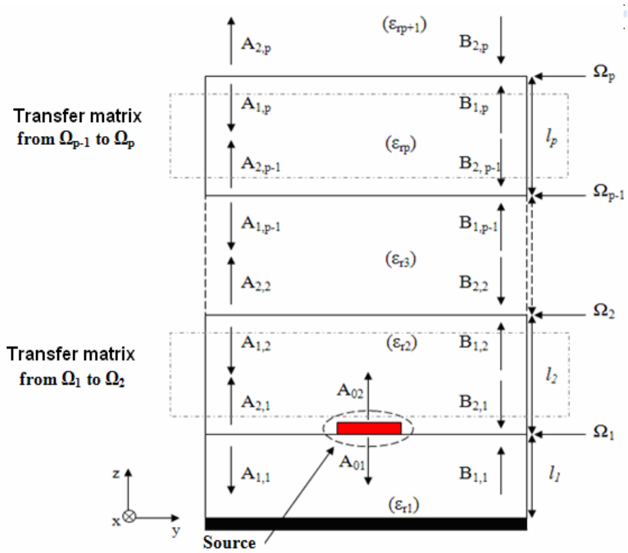

Fig. 2. Transfer matrix, waves and source in a multilayer structure

The incident (A) and reflected (B) waves, and the electric field (E) and current density (J) can be related by:

$$A_i = \frac{1}{2\sqrt{Z_{0i}}}\left(E_i + Z_{0i} J_i\right) \quad (1)$$

$$B_i = \frac{1}{2\sqrt{Z_{0i}}}\left(E_i - Z_{0i} J_i\right) \quad (2)$$

Where, Z_{0i} is the characteristic impedance of medium *i*.

The usually used WCIP scheme is very simple. It can be represented by the following two equations:

$$A = SB + A_0 \quad (3)$$

$$B = \Gamma A \quad (4)$$

Where, $\boldsymbol{A}_0$ is the local source of the circuit.

Here, a new relationship formulation between waves (A_{p-1}, B_{p-1}) and (A_p, B_p) is introduced for the transformation between two adjacent interfaces. This formulation is obtained from the impedance matrix of a transmission line.

$$\begin{bmatrix} B_{p-1}(k_x,k_y) \\ B_{p-1}(k_x,k_y) \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}_{m,n} \begin{bmatrix} A_p(k_x,k_y) \\ A_p(k_x,k_y) \end{bmatrix} \quad (5)$$

Where

$$[T] = \begin{bmatrix} \dfrac{(Z_c^2 - Z_{0i}^2)\sinh(\gamma l)}{2Z_c Z_{0i}\cosh(\gamma l) + (Z_c^2 + Z_{0i}^2)\sinh(\gamma l)} & \dfrac{2Z_c Z_{0i}}{2Z_c Z_{0i}\cosh(\gamma l) + (Z_c^2 + Z_{0i}^2)\sinh(\gamma l)} \\ \dfrac{2Z_c Z_{0i}}{2Z_c Z_{0i}\cosh(\gamma l) + (Z_c^2 + Z_{0i}^2)\sinh(\gamma l)} & \dfrac{(Z_c^2 - Z_{0i}^2)\sinh(\gamma l)}{2Z_c Z_{0i}\cosh(\gamma l) + (Z_c^2 + Z_{0i}^2)\sinh(\gamma l)} \end{bmatrix} \quad (6)$$

III. Simulation Results

In order to present the performance of the proposed tool, a simulation of a slot coupled patch antenna was conducted. Figs. 3 and 4 show the multilayer structure with different interfaces. On the first interface, the microstrip feed line has width of 1.9 mm and length of 14.7 mm. On the second interface, the slot has width of 4.7 mm and length of 0.6 mm. The patch on the third interface has width of 16 mm and length of 6.65 mm. The waveguide is 22 mm wide and 22 mm long, $\varepsilon_{r1} = \varepsilon_{r4} = 1$, $\varepsilon_{r2} = \varepsilon_{r3} = 3.38$, $l_2 = l_3 = 0.81$ mm.

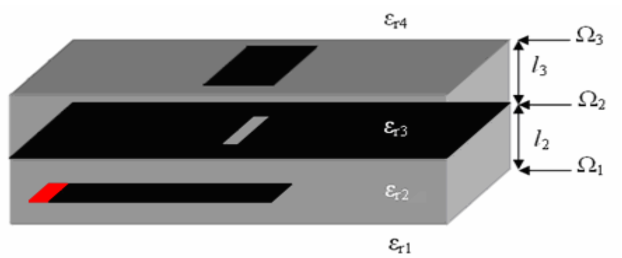

Fig. 3. 3-D view of the slot coupled patch antenna structure

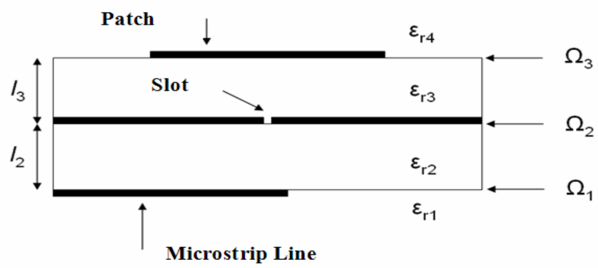

Fig. 4. Slot coupled patch antenna structure side view

As can be seen in Fig. 5 (blue curve), the resonance frequencies simulated results are very close to the measured frequencies. Also, this is in good agreement with the measured frequency presented in [6]. Therefore, it can be used to confirm that the method proposed herein gives satisfactory results, as they are closer to the measured ones than those of the simulations in [6], with a comparatively small computational effort. The computation time for the complete simulation is about 45 minutes on an Intel Core 2 Duo 2.53 GHz CPU.

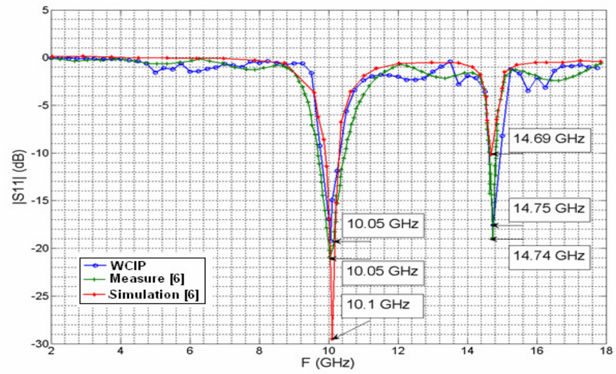

Fig. 5. Absolute value of the input reflection coefficient, $|S_{11}|$ in dB as a function of frequency in GHz

IV. Conclusion

In this paper, an implementation of the WCIP for multilayer structure analysis is presented. A slot coupled patch antenna has been analyzed and simulated. The obtained results show that the method herein formulated and computationally implemented is suitable to electromagnetic analysis of multilayer planar circuits. Very good agreement among simulated results, available theory, and physical implementation has been achieved.

Acknowledgment

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V. References

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