A NOVEL 2-D MULTI-MODE PARALLEL TIME DOMAIN DIAKOPTICS AND ITS APPLICATION IN FILTER ANALYSIS AND DESIGN

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ABSTRACT

A novel two-dimensional multi-mode parallel time domain diakoptics based on FDTD is proposed. The discrete time domain Green's function is employed to analyze complicated circuits entirely in time domain with greatly improved efficiency. A part of the results is combined with frequency-domain synthesis method to design a band-pass filter. Excellent agreement with mode-matching and measured results is obtained.

INTRODUCTION

In order to rigorously analyze microwave integrated circuits, several time domain diakoptics methods are available. These include the Transmission Line Matrix diakoptics(TML-Diakoptics)[1], the Finite-Difference Time-Domain diakoptics (FDTD-Diakoptics) [2] and the modal absorption in the FDTD[3]. While time domain diakoptics can be used to implement a wide-band absorbing boundary condition close to circuit discontinuities [1][3][4][5], one more important application is in the analysis and design of electrically large structures. It is well known that time domain techniques such as FDTD and TLM are inefficient in analyzing large, complicated circuits accurately. Diakoptics can provide an efficient solution to this problem by breaking the circuit into individual sub-sections. In [2], a one-dimensional circuit was treated successfully by dividing into several subsections using the diakoptics concept.

In this paper, we propose a novel two-dimensional multi-mode parallel time domain diakoptics based on FDTD. This approach allows us to minimize the region and the number of discontinuities to be analyzed in a circuit, resulting in an accurate and efficient analysis and design tool for large structures with complicated geometries. The time domain parallel algorithm is then introduced. Results are given which are in good agreement with those obtained by mode-matching and measurement. Finally, a portion of the results obtained by the proposed algorithm is combined with a synthesis method following [6],[7] to successfully design a bandpass filter with specified characteristics. The advantage of the proposed approach is that it can be applied to a much wider class of problems which may be difficult to solve using most conventional techniques.

2-D MULTI-MODE DISCRETE TIME DOMAIN GREEN'S FUNCTION

$$y_i(n) = \sum_{j=1}^{M} \sum_{n'=1}^{n} g(i, j, n-n') \cdot x_j(n') \quad i = 1, ..., M$$

In linear system theory, the input and output of a multi-port system have the following relations where $g(i,j,n')$ is the impulse response at port i at $t=n'$, due to the unit excitation at port j at $t=0$. $x_j(n')$ is the input at port j at $t=n'$, $y_i(n)$ is the output at port i at $t=n$.

Fig.1(a) shows one section of a waveguide containing a discontinuity. When an incident field is applied at plane 1, higher order modes exist at the plane 2 along with the dominant mode. The field at plane 2 is decomposed by [*sin, cos*] orthogonal functions which we refer to as 'modes' in both frequency and time domains. Although for an empty rectangular waveguide, these functions are the same as the waveguide modes, generally they are different.

Based on the concept of diakoptics, this multi-mode structure is equivalent to a multi-port circuit (Fig.1(b)), where each port corresponds to one waveguide mode. Fig.2 shows the transient response of Fig. 1(a) at plane 2 due to the dominant mode excitation. It is clear that higher order modes exist at this plane. Hence, the multi-mode Green's function must be used.

CASCADING OF STRUCTURES

When impulse responses of all subsections are pre-calculated, the larger circuit (for example: Fig. 3(a)) can be analyzed by cascading all subsections together. The analysis of large complicated circuits can be done either by the sequential or parallel algorithm. In the sequential algorithm the simulation is carried out sequentially from the outer to inner subsections. The limitation of the sequential algorithm is that a modification in one subsection will affect its inner sections. All inner subsections must be simulated again, although most of them do not change.

The parallel algorithm can overcome this limitation. The subsection is treated as a two port or multi-port circuit. The matrix-type connection condition is employed to deal with the interaction between two neighboring subsections (as show in Fig.3(b)). It is similar to the Generalized Scattering Matrix Technique [8]. In time domain, the impulse responses of the whole circuit can be expressed:

$$G_{11}^{T} = G_{11}^{1} + G_{12}^{1} * G_{11}^{2} * G_{21}^{1} + G_{12}^{1} * G_{11}^{2} * G_{22}^{1} * G_{11}^{2} * G_{21}^{1} + \cdots$$
$$G_{21}^{T} = G_{21}^{2} * G_{21}^{1} + G_{21}^{2} * G_{22}^{1} * G_{11}^{2} * G_{21}^{1} + \cdots$$
$$G_{12}^{T} = G_{12}^{1} * G_{12}^{2} + G_{12}^{1} * G_{11}^{2} * G_{22}^{1} * G_{12}^{2} + \cdots$$
$$G_{22}^{T} = G_{22}^{2} + G_{21}^{2} * G_{22}^{1} * G_{12}^{2} + G_{21}^{2} * G_{22}^{1} * G_{11}^{2} * G_{22}^{1} * G_{12}^{2} + \cdots$$

where $G_{11}{}^{i}$,$G_{12}{}^{i}$,$G_{21}{}^{i}$ and $G_{22}{}^{i}$ ($i=1,2$) are sub-matrices whose dimensions depend on the number of modes considered. The subscript indicates the output and input port number, and the superscript indicates the subsection number.

Fig.4 compares the results of diakoptics and FDTD of Fig. 3(a). Two diakoptics results are given. One is the dominant mode diakoptics and the other is the multi-mode diakoptics (2 modes). Using the multi-mode diakoptics improved the result significantly.

FILTER ANALYSIS

The E-plane metal-insert filter of [9] is analyzed by using this method, as shown in Fig. 5(a), which is symmetric with respect to plane *A-A'*. Several ways can be used for this structure. One is that the whole filter is entirely analyzed by FDTD, which takes very long computation time. Another is that each inserted metal is looked upon as one discontinuity, then all subsections are cascaded together. In this case, two sections, I and II, must be calculated. However, we used yet another method. FDTD is used to generate numerical Green's function of the immediately neighborhood of the sharp edge indicated as Ω_1 and Ω_2 . Because all edges are identical, only one fine mesh FDTD analysis of a small resgion (Ω_1) suffices. For the rest of the structure, which consists of waveguide sections of different dimensions, two computations with coarse meshes can be used. So, the method we propose is very efficient. The results are shown in Fig. 6.

FILTER DESIGN

To be an efficient tool for synthesis, an optimizer has to be combined with the FDTD diakoptics analyzer. As a first step to this end, we incorporated the results of the discontinuity analysis into an available optimizer and attempted a filter design. The region near an edge discontinuity as shown in Fig.7 (a) is analyzed by FDTD. This result is transformed to frequency domain to obtain a generalized scattering matrix. Using the generalized scattering matrix in a synthesis procedure, we design an E-plane metal-insert filter. Table 1 gives the design specifications and the optimized dimensions. The result obtained by using mode-matching with the same procedure is given, too. To check that the discrepancies in the dimensions obtained with the two approaches are not significant, the two structures are analyzed by mode-matching. The results, shown in Fig. 8, demonstrate that the accuracy is sufficient. Although this structure can be efficiently analyzed or synthesized by mode-matching, in many other structures FDTD diakoptics is necessary in order to get accurate result.

CONCLUSION

A novel two-dimensional multi-mode parallel time domain diakoptics has been presented. The technique has been applied to several structures. Results agree well with published data. This technique has been shown to be efficient for analyzing complicated structures. The hybrid technique presented here, which combines time domain diakoptics with synthesis design method, should prove to be a powerful design tool applicable to a wide class of problems which are currently difficult to analysis with existing techniques, such as mode-matching combined with synthesis.

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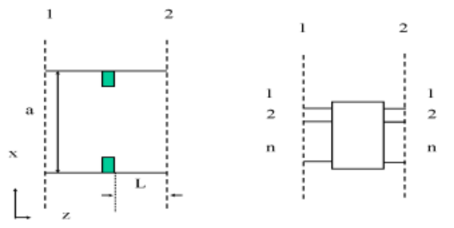
Table 1. Design Requirement and Results

	F_0 (GHz)	Lower cutoff Freq. F_1(GHz)	Higher cutoff freq. F_2(GHz)	Stop band freq. F_a(GHz)	Stop band freq. F_b(GHz)	Ripple level in passband (dB)	Insert Loss of stopband (dB)	L_1(mm) (=L_3)	L_2(mm)	D_1(mm) (=D_4)	D_2(mm) (=D_3)
Specification	32.523	32.306	32.734	30.0	35.0	0.05	30.0				
This method	32.523	32.306	32.734	30.0	35.0	0.05	30.0	4.76542	4.78679	0.8179	3.3134
Mode-Matching	32.523	32.306	32.734	30.0	35.0	0.05	30.0	4.76417	4.78728	0.8023	3.2942



(a) Inductive discontinuity

(b) Equivalent multi-port circuit of (a)

Fig.1 Geometry of one section of discontinuity inside a waveguide.

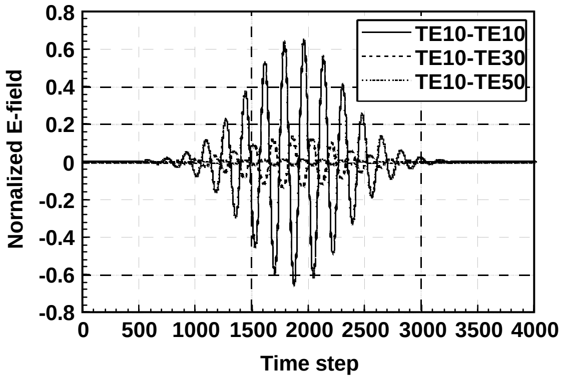
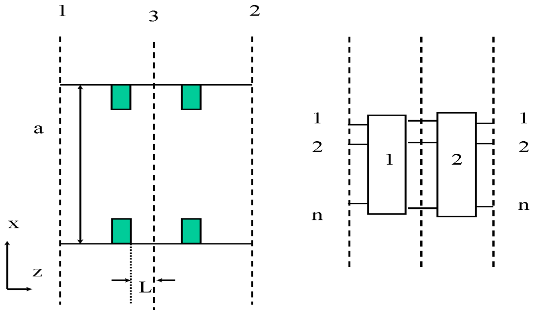


Fig.2 Transient responses of each mode at plane 2



(a) Inductive discontinuity

(b) Equivalent multi-port circuit of (a)

Fig. 2 Cascading of structures

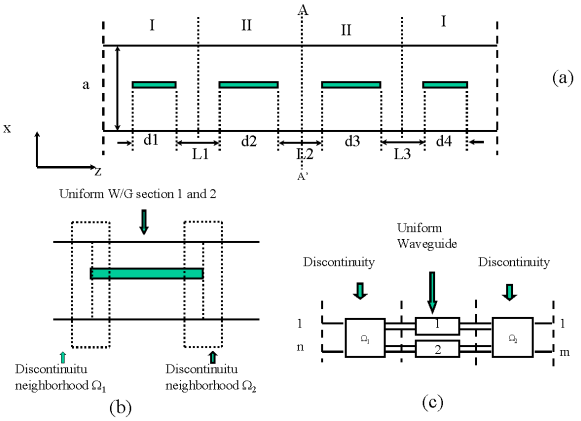


Fig.5 Geometry and analysis model of an E-plane filter with metal insert. (a) All metal inserted E-plane filter, (b) One section of (a), (c) Equivalent multi-port circuit of (a)

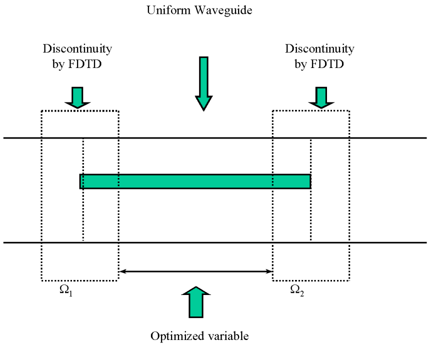


Fig. 7 E-plane metal insert filter design model of each section

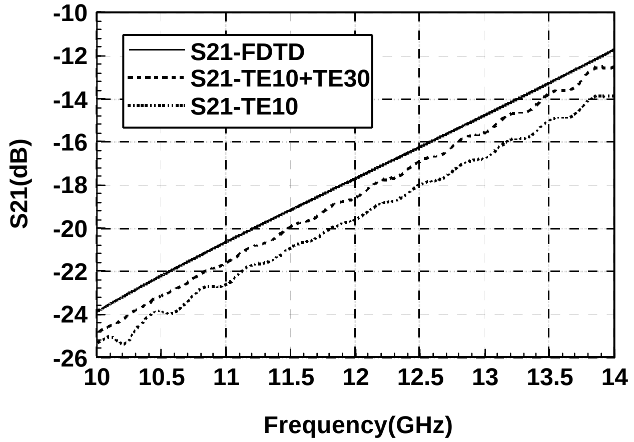


Fig. 4 Comparing direct FDTD and the proposed method: effect of higher modes.

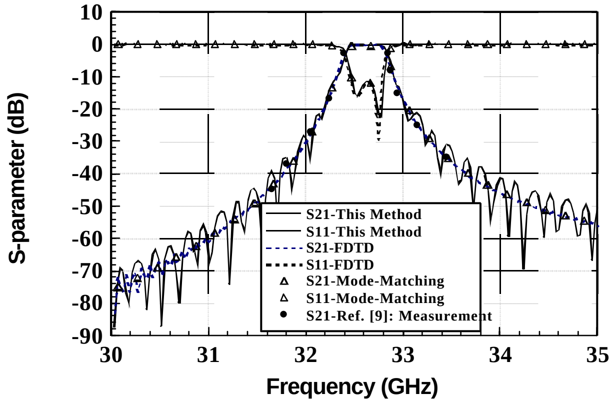


Fig. 6 Comparing the results of this method, mode-matching and measurement in Ref.[9].

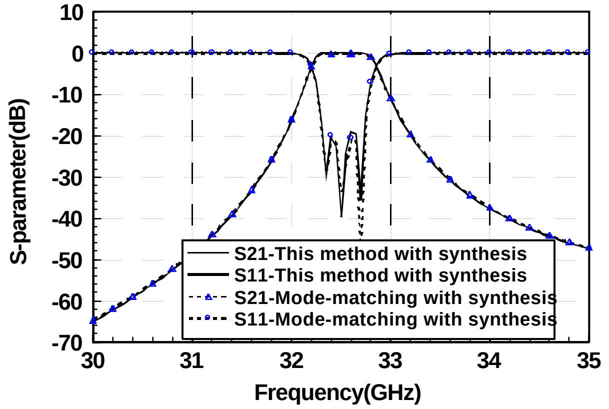


Fig. 8 Mode-matching analysis of the optimized E-plane metal-inserted filter.

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