

Domain Decomposition FDTD Algorithm for the Analysis of Electromagnetic Fields and Microwave Structures

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Abstract

In this paper, a universal and efficient algorithm of domain decomposition finite difference time domain (DD-FDTD) is presented for the analysis of electromagnetic fields and microwave structures. The proposed algorithm can not only be used to analyze very complicated microwave structures but also be used to analyze sparse multi-domain electromagnetic fields. The algorithm can greatly increase the accuracy of numerical simulations and save computation time and memory space. Moreover, by combining the DD-FDTD method with a numerical thru-line (TL) calibration technique, an efficient hybrid algorithm is developed for the accurate parameter extraction of microwave circuits and structures, such as substrate integrated circuits (SICs). The SICs that are studied in this work are based on substrate integrated waveguides (SIW) which are useful for the design of millimeter-wave planar circuits such as filters, resonators and antennas.

1. Introduction

The finite difference time domain (FDTD) method, first introduced by Yee [1], is a powerful, robust, and popular modeling algorithm based on the direct numerical solution of Maxwell's equations in the differential, time domain form. The most important feature of the FDTD method is that broad-band frequency information can be provided in a single-pass simulation. It has been extensively used in the parameter extraction of waveguides [2-7], microstrip circuits [8-10] and multiple coupled lines [11, 12].

In the researches and applications, three main drawbacks of the FDTD method have been discovered. The first one is that a suitable meshes scheme is very difficult to be obtained when the simulated structures of antennas, circuits or systems are very complicated. In this case, a locally conformed scheme relying on the integral form of the Maxwell's equation [13, 14] or an additional local coordinate system near the complicated structures combined with an interpolation technique in the overlapping region [15] can be used. The second is related to the sparse multi-object simulation in which the distances among these objects are very large. A considerable amount of meshes have to be arranged between objects to finish the transfer of EM information. In this case, multiple-region FDTD (MR/FDTD) method [16, 17] and a discrete wavelet transform (DWT) based on compression technique [18, 19] can be used to decrease the cost of near-field to near-field transform. The third is how to set up a suitable excitation source on a complicated structure port and how to extract the parameters of these circuits and components, for example, a circuit based on the substrate integrated waveguide (SIW) which has been widely discussed and developed recently.

By combining the idea of domain decomposition with the FDTD method, one can find that the three drawbacks can be easily overcome. In the first case, by decomposing the complicated structure into some simple sub-domains and using different local coordinate meshes according to each sub-domain structure, the simulation will be simplified significantly if a suitable interpolation technique is used [20]. For the second case, the idea of domain decomposition is introduced to divide the sparse problem domain into several sub-domains. The DD-FDTD method is based on near-field to far-field transform and equivalent incident field [21, 22]. The time-domain Green's function is used to fulfil the fields transfer. As a result, a large amount of meshes between the sub-domains are removed. In the third case, a numerical thru-line (TL) calibration procedure, which allows for a very accurate extraction of dynamic circuit parameters, will be combined into the DD-FDTD method [23].

2. DD-FDTD Algorithm

The simplicity and usefulness of the FDTD method in solving Maxwell's equations is well known and its application is widespread. Based on this idea, the simulation domain is decomposed into several sub-domains corresponding to the small-structures and the meshes are created in local coordinates. In each sub-domain, the FDTD computation is carried out independently in local meshes and local time step, and there is no stability concern.

2.1 Complicated Structure

When a microwave structure is quite complicated, for example, an E-plane horn as shown in Fig.1, the whole horn is decomposed into several sub-domains corresponding to the small-horns and the meshes are created in local coordinates. In the overlapped region between adjacent sub-domains, the meshes corresponding to different sub-domains are not coincident. Thus, interpolation is adopted to transfer the data from one sub-domain to another. The details can be found in [20].

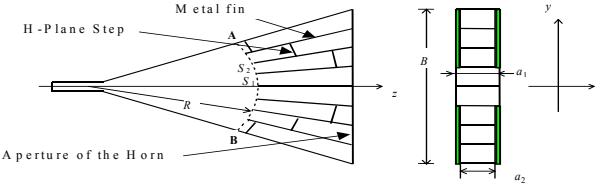


Fig.1 E-plane sectorial horn with aperture field distribution optimization

2.2 Sparse Multi-Objects Electromagnetic Simulation

Each object is regarded as single sub-domain by using DD-FDTD method to resolve the sparse problem. Except the coupling, the FDTD iterative calculation of each sub-domain is just like that of single domain problem. If the sub-domains are apart away some distances, the coupling can be regarded as the equivalent cylindrical waves [21] or spherical waves [22] incident fields.

For example, as shown in Fig.2, the coupling of cylinder A to cylinder B is approximately regarded as a cylindrical wave incident field. As we know, the incident field is inputted on the total field-scattered field separation surface and the introduction of incident field array (IFA) simplifies the input of incident field and decreases the calculation time significantly. The more discusses can be obtained in [21, 22].

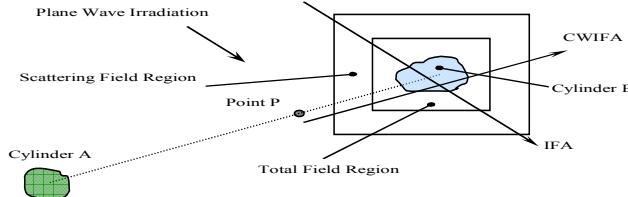


Fig. 2 CWIFA model for the interactions calculation.

2.3 TL Calibration and DD-FDTD Algorithm

The idea of developing a hybrid algorithm stems from the need to extract parameters of substrate integrated circuits (SICs). When the FDTD method is used to extract the parameters of SICs, the source cannot be set up inside the SIW and the excitation and reflection signals cannot be separated due to multi-reflections and diffractions. To solve this problem, we connect the SIW component with two virtual normal waveguides with sizes relevant to the SIW, as shown in Fig.2. Then, by using the FDTD method, we can extract the parameters at AA'.

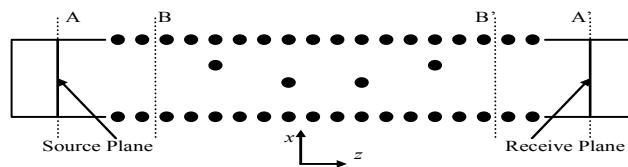


Fig. 3. FDTD simulation scheme of SICs.

4. Numerical Results and Measurement Data

The E-plane pattern of a six-element array which is consisted of the E-plane horn shown in the Fig.1 is illustrated in Fig.4. The central work frequency is 5.35GHz. The good agreement between the numerical results of the DD-FDTD algorithm and the measurement can be observed.

As shown in Fig.5, two mixed cylinders construct 2-D scattering problemIn Fig.5, the bistatic-RCS result of DD-FDTD method is in agreement with that of classic FDTD method.

At last, a SIW offset post filter as shown in Fig.6 is investigated. The details of structure sizes can be referred [23]. Fig.7 shows results of our hybrid method simulation and measurements. The simulated results agree with the measured results.

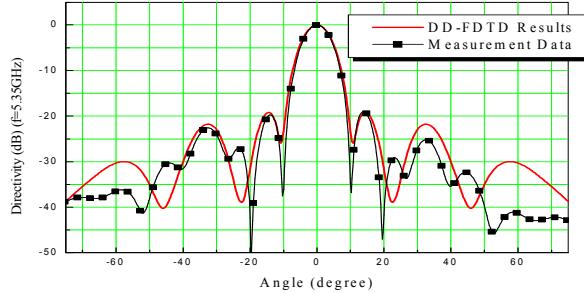


Fig.4 E-plane pattern of the metal lens horn antenna ($f=5.35\text{GHz}$).

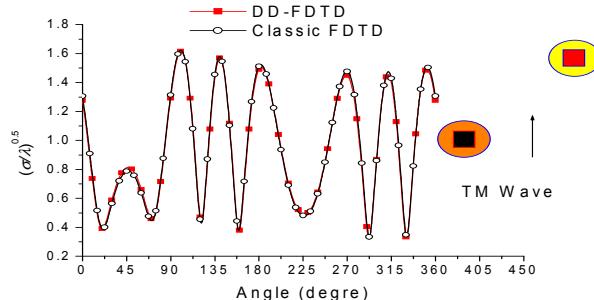


Fig.5 Bistatic-RCS of two mixed cylinders, the spacing is 300mm, frequency is 2GHz, the incident direction is that of $\varphi=90^\circ$.

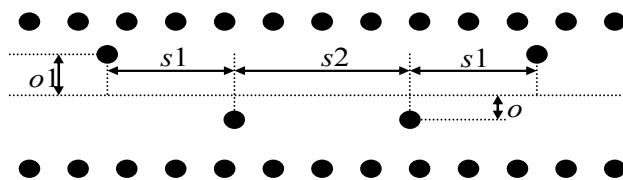


Fig.6 Topology of the offset post filter of identical post diameter.

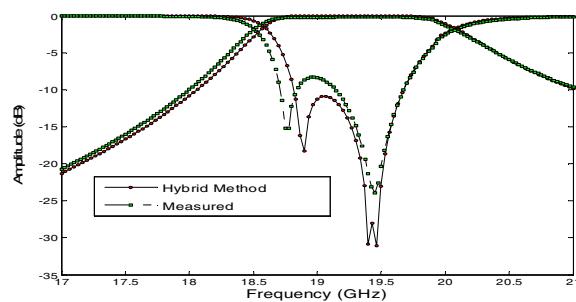


Fig.7 Measured and simulated scattering parameters of the inductive post-filter.

Conclusion

An idea of domain decomposition is discussed. When the idea is combined with the FDTD method, the main drawbacks of the method can be broken through. This kind of the DD-FDTD method has large flexibility, simplicity, efficiency and accuracy. Many complex problems that cannot be solved using most traditional methods can be easily calculated and analyzed by use of the DD-FDTD method. The TL numerical calibration technique can flexibly be integrated with various types of numerical methods, such as the FDTD method, to extract circuit parameters in a quick and accurate manner. Moreover, the hybrid algorithm allows for time domain methods to be used in the analysis of SICs. Our comparative investigations have demonstrated that the proposed numerical method is able to quickly extract the parameters of these circuits. The introduction of the domain decomposition scheme simplifies the simulation process and increases the numerical reliability and algorithmic applications.

6. References

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