A NOVEL DOMAIN DECOMPOSITION TECHNIQUE FOR SOLVING VERY LARGE PROBLEMS IN FREQUENCY AND TIME DOMAINS

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Abstract

In this paper, we describe some novel approaches to solving large problems in frequency and time domains. The frequency domain approach is based on the characteristic Basis Function Method (CBFM), while the time domain scheme is called the serial-parallel approach. The common thread between them is that they both utilize the domain decomposition (DD) approach, but without resorting to iteration.

Introduction

Solving large problems is always challenging since they place considerable burden on the available computer resources. Traditionally, we have resorted to asymptotic methods— such as ray techniques— to handle these problems. However, many real-world problems are not amenable to analysis using asymptotic methods, because of their complex, inhomogeneous and multiscale nature that must be dealt with via numerically rigorous techniques. The available size of the RAM on the computer typically determines the problem size that it can accommodate, and the solve-time is determined by its flop rate.

In this paper we describe two strategies for solving large problems, in frequency and time domains, respectively. Though the algorithms we describe for solving the problem in these two domains are totally different, they do have one important attribute in common, namely they are based on decomposing the large problem into a number of smaller ones. In of itself, this strategy of Domain Decomposition (DD) is not new, at least in the frequency domain. What makes our approach different is that instead of relying upon iterative techniques—as is typically the case when using conventional DD methods—the method presented herein transforms the original large matrix into one whose size is small enough to be conveniently manageable. The paper will present an example where a moderately large problem, requiring upward of 100K+ unknowns is solved on a single-processor PC.

Next, we will describe the important step of parallelization, which not only enables us to solve much larger problems, but also allows us to do this in a numerically efficient manner because the algorithm we employ is inherently parallelizable; and, hence, it scales are very well as the number of processors is increased. Some numerical examples are presented in Figs. 1 through 5 to illustrate the application of the frequency domain algorithm that combines DD with parallelization.

Let us now turn to the time domain analysis of large problems, again using the Domain Decomposition approach, but this time employing the FDTD algorithm —which is a relatively new concept. It is well known that FDTD is an explicit technique; hence we are not concerned here with the size of the matrix. However, if the number of Degrees of Freedom (DoFs) associated with a given problem is so large that it cannot be accommodated in the available RAM, even on a platform with multiple processors; we divide the original problem into a number of smaller ones. However, in contrast to the frequency domain DD approach, described above, we always subdivide the given problem by slicing it in only one direction, and not arbitrarily as we do in the frequency domain. Also, we take advantage of the physics of time domain propagation, and solve the problem sequentially in time, tracking the propagation of the wave from one end of the object to the other. The method is designed to solve EMC/EMI problems when the coupling between two antennas that are located some distance from each other and, hence, the coupling between them is relatively weak. Another example is that of a Cassegrainian feed system, comprising of a feed horn and a subreflector that may have complex geometries and material characteristics. We show via these examples how we can reduce the original large problem into a small one whose size is much more manageable.

Figures 6 through 14 below illustrate the apllication of Domain Decomposition (DD) method in the time domain—also referred to as the Serial-Parallel Technique—to two scattering problems involving long objects, as well as to an EMI coupling problems pertaining to coupling between two antenna arrays.

Figures

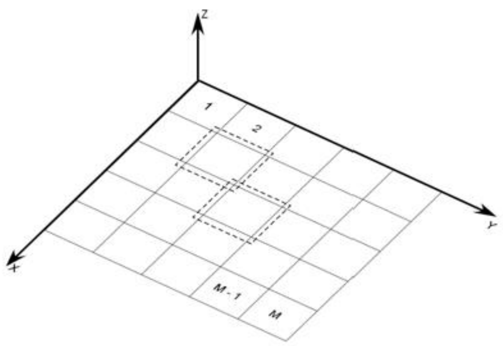


Fig.1. Plane wave spectrum for generating the characteristic basis functions.

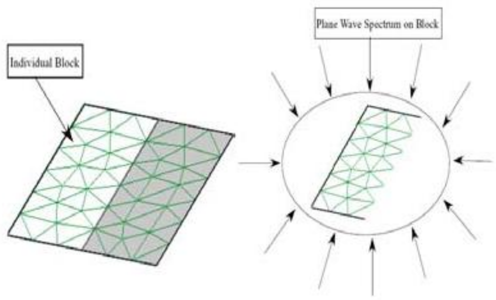
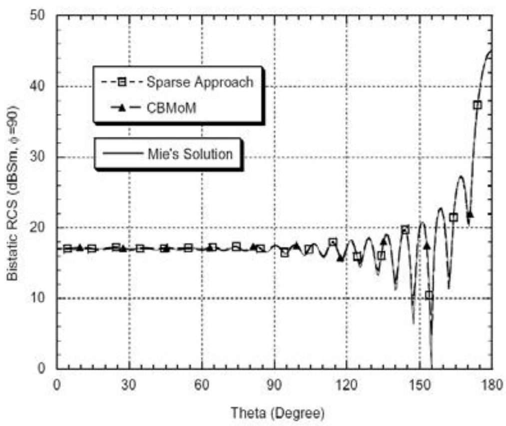


Fig.2. Illustrative example of a PEC plate plane wave spectrum for a single block is represented with dashed line.



a)

Fig.3. RCS of 4λ radius PEC sphere at 0.3 GHz: a) E-plane; b) H-plane.

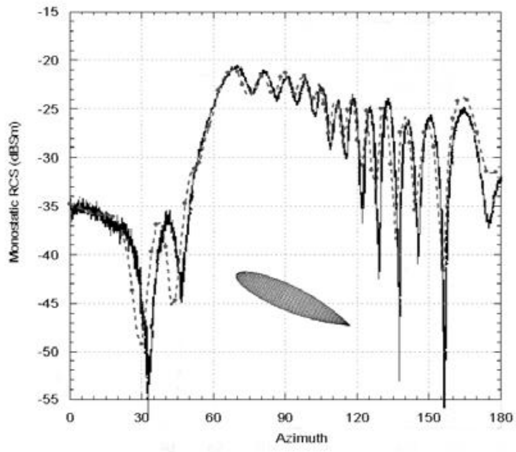


Fig.4. The NASA metallic Almond at 7 GHz, for horizontal polarization, computed by using this method (dashed line with dots) and compared against measurements (continuous line).

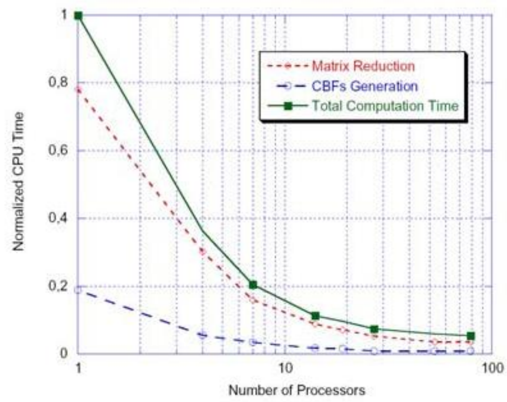


Fig.5. Performance of Parallelized CBMoM code, on a 80 processor platform.

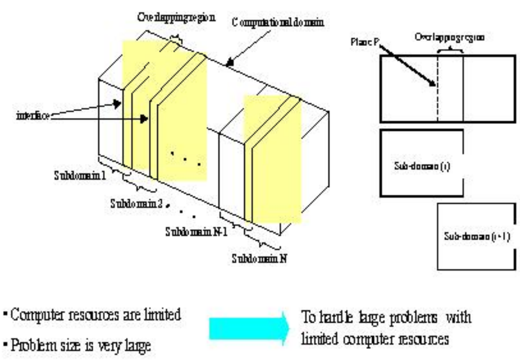


Fig.6. Basic concept of the serial-parallel Approach which can enhance the problem solving Domain Decomposition in FDTD and Serial-Parallel Approach.

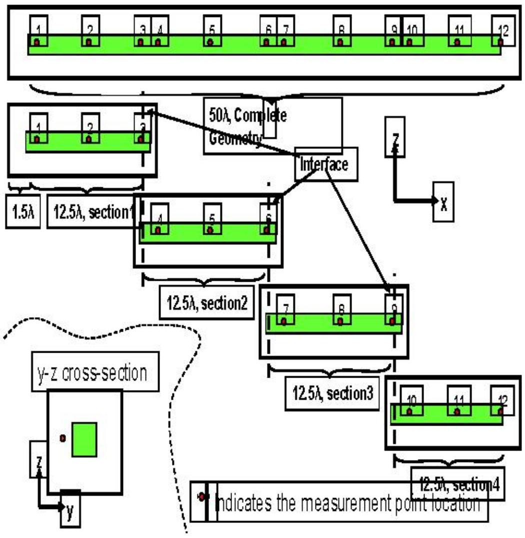
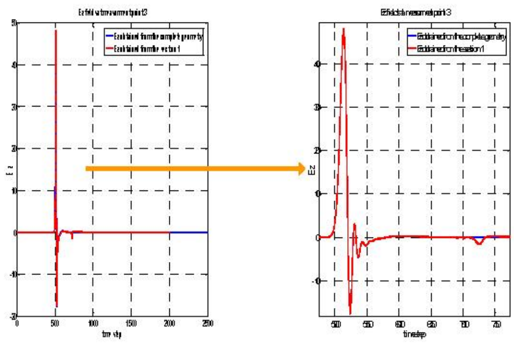
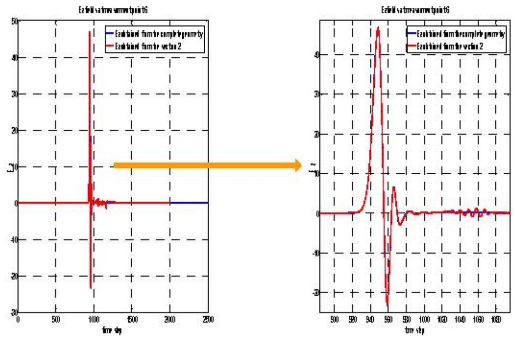


Fig.7. Domain decomposition of a long scatterer.



(a)



(b)

Fig.8. Comparison direct and DD solutions.

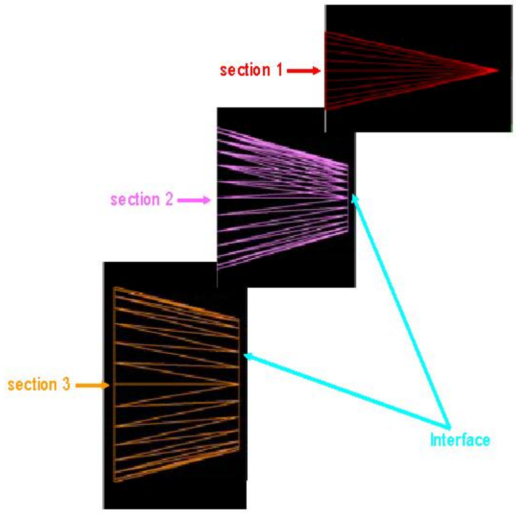


Fig.9. Domain Decomposition of a conical scatterer.

Domain Size
- x-direction = 318 mm = 53?
- y-direction = 216 mm = 36?
- z-direction = 216 mm = 36?

Cell Size
x-direction = 0.3 mm = ?/20
y-direction = 0.3 mm = ?/20
z-direction = 0.3 mm = ?/20

Object Size
- height = 300 mm = 50?
- Bottom Radius = 60 mm = 10?
- Overlapping = 18mm = 3?

Excitation
3-dB freq = 50 GHz
modulated freq = 0
direction of the plane-wave: axial

Simulation
- number of time steps = 2500
- simulation time = 1 hour and 26 min on BlueGene Supercomputer using 3900 processors

Fig.10. Modeling and simulation detail for scatterer in Fig.9.

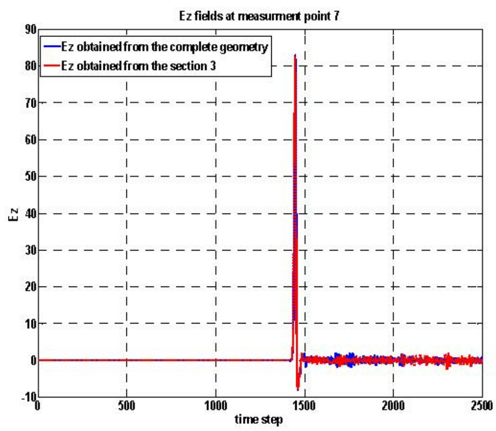


Fig.11. Comparison of DD and direct solutions for scatterer in Fig.9.

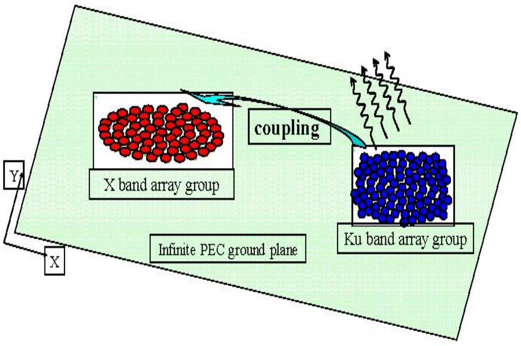


Fig.12. Array coupling problem.

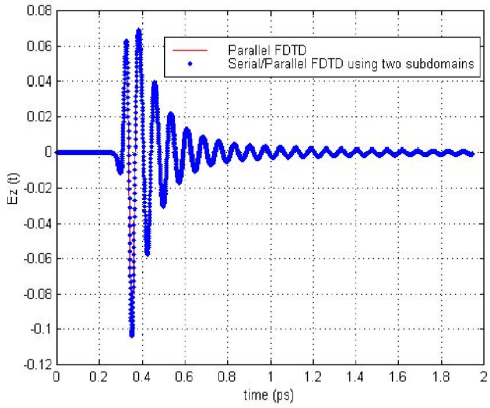


Fig.13. Comparison of time domain signatures for the array coupling problem in Fig.12.

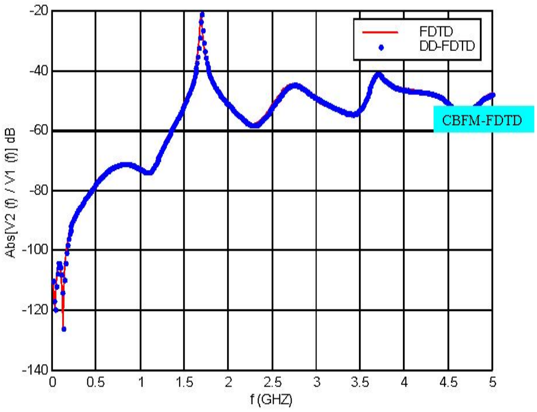


Fig.14. Comparison of the coupling levels DD and Direct solution for the array coupling problem.

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References

For extensive bibliography on this and related subjects, please refer to Raj Mittra's website: http://www.personal.psu.edu/rxm53/