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Advances in FETI methods for the simulation of multi-source electromagnetic problems

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Abstract - **We present the performances of new way of using Krylov type algorithms in FETI methods for solving multi-source electromagnetic problems.**

Index Terms - **Finite Element Tearing and Interconnecting, Antenna Array, Antenna Radiation, Antenna RCS, Krylov spaces.**

1. Introduction

The finite element method (FEM) is particularly well suited to the modeling of antennas and scattering problems including non-homogeneous materials, and anisotropic materials. It is naturally implemented in the characterization of metamaterials consisted of periodic juxtaposition of building blocks formed with multi layers dielectrics and perfectly conducting surfaces. In this context, ONERA has been engaged for many years in the development of Finite Element Tearing and Interconnecting (FETI) methods and their implementation on parallel machines with thousands of processing cores. The FETI solver is implemented in the multidomain FACTOPO code which was brought in 2015 on the Occigen cluster of the CINES French national center in the framework of computing hours made available by the GENCI consortium. A very good scalability of our FETI algorithms has been demonstrated, for sizes of volume problems ranging from 300 million to 2 billion unknowns resolved in less than 11 minutes in the framework of array antenna and metamaterial simulations. Furthermore, the ORTHODIR iterative resolution of such problems using Krylov methods with complete re-orthogonalization of the search directions vectors. If the same electromagnetic problem must be resolved for several right and side (incident plane wave or power ports of an array antenna) iterative techniques require a complete new resolution which is very expensive. In this work, multi-right-hand algorithms by blocks with deflation were then developed together with FETI algorithms for obtaining gains in computing time of about 20 and 40 on industrial applications of modest size (17x17 and 16x1 network). These gains are much higher for larger periodic structures.

2. Recent new way of using Krylov recycling algorithms

During the SAFAS research program [1] an antenna array with low RCS levels was investigated and designed. The SAFAS antenna is obtained by periodization of the unit cell described on Fig.1 for which the leading dimension is 7.07 mm and the height is 20 mm. An equivalent circuit model was implemented for optimizing the unit cell containing dielectric layers, thin perfectly conductive surfaces and thin 150 Ohms resistive surfaces [3].

The FETI-2LM method was implemented in order to evaluate the RCS reduction performance of the antenna depending on its size while taking into account the diffraction effects caused by the edges of the array. The RCS reduction is obtained by subtracting the finite array RCS with the RCS of a perfectly conducting flat plate of same size. Both scalability of the FETI-2LM method and RCS reduction efficiency of the mock-up is analyzed by considering arrays with progressively increasing size (22x22, 28x28, 56x56 and 85x85). The simulation results are obtained with the one order Hcurl finite element and four empty unit cells are placed around the arrays to keep the Absorbing Boundary Conditions (ABC) sufficiently far away from the scatterer. Note that the surface of the greater array is 60.1x60.1 cm2, the total number of unknowns is 2.05 billion, the total number of interface equations is 254.5 million and the number of core processors used is 13,056. The Fig.2 shows the excellent scalability of the FETI-2LM method and the elapsed time observed for the 4 arrays investigated. The elapsed time of 10 minutes per frequency is obtained on the Xeon Haswell cluster for a convergence lower than 10^{-3}. The RCS reduction levels obtained with the SAFAS antenna concept are plotted on Fig.3. The FETI-2LM simulations of the 22x22,28x28,56x56 and 85x85 finite arrays are compared with infinite array solution provided by the CST Microwave Studio commercial software. We observe that the simulated RCS reduction at normal incidence is between 10 dB and 27 dB for the frequency band 3-19 GHz.

Multiple right hand side algorithms recently proposed in [4] are assessed for the previous antenna. We consider a uniform plane wave exciting a 7x7 array completed by 5 empty unit cells around it constituting finally a 17x17 array. The total number of unknowns is 68.34 million and the total number of interface equations is 5.6 million. We are considering 32 incidence angles varying from (θ=0,φ=0) to (θ=31,φ=0). All the simulations are implemented on nodes with 2 Intel Xeon Haswell processors clocked at 2.6 GHz and each equipped with 12 cores.

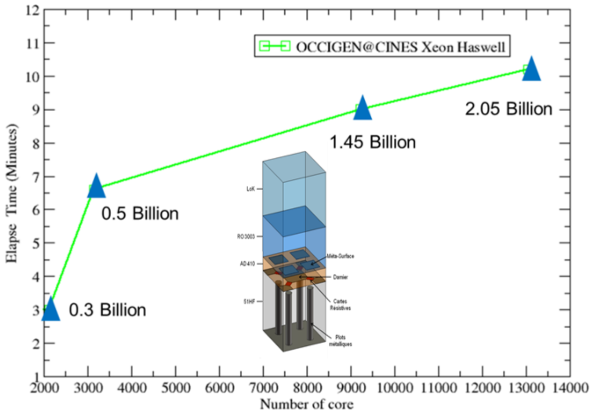

Fig. 1. SAFAS unit cell and scalability on the CINES Occigen cluster

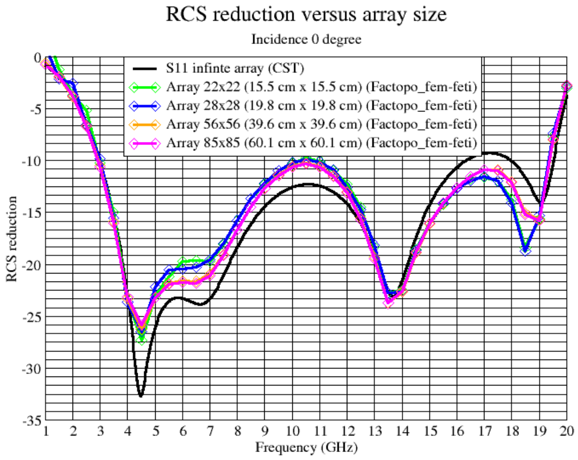

Fig. 2. RCS reduction versus array size at normal incidence

Simulations of the 17x17 array are implemented by 289 MPI processes running on 289 core processors, that is to say one unit cell is affected to one core. In the simulations using the Initial Krylov Recycling strategy (IKRS) we allocated 24 MPI processes per node and therefore used a total of 13 Xeon Haswell nodes. The setting is different for simulations of the same test case with multiple right hand side by Block Recycling Krylov strategy (BKRS). Indeed, in order to accelerate the construction and use of the blocks of Krylov search directions for RHS packets processed simultaneously (two packets of 16 in this case), we allocated only 2 MPI process par node and 12 threads per MPI process and therefore used a total of 145 nodes. On Fig.3 we observe that the number of FETI iterations required for convergence is significantly reduced by a factor 5 for the 17x17 array from the second incidence. We then see a stabilization of the number of iterations between 40 and 60 for the incidences between 1 and 20 degrees following by a constant rise beyond 20 degrees. Comparatively to the sequential approach where the iterative resolution is restart from scratch for each new incidence, we have observed a speed up of 2.6 of the elapsed time if we use the IKRS strategy and a speed up of 20 with the BKRS strategy which requires 21% memory more. We recall that for this simulation, the electromagnetic plane wave sources are uniformly illuminating the array over its entire surface. The induced currents obtained for directions of incidence fairly close (1 degree in our setting) are relatively similar which makes the initial strategy by projection already very effective as observed on the convergence curve of Fig.4.

TABLE I
Performances of IKRS and BKRS strategies; 68.34 million unknowns, 5.6 million interface equations

	Grid	RHS	Stored directions	Elapsed Time (H)	Memory (Gb)
Sequential	17x17	32	3000	9.6	1.9
IKRS	17x17	32	3000	3.57	1.9
BKRS	17x17	32	3000	0.48	2.3

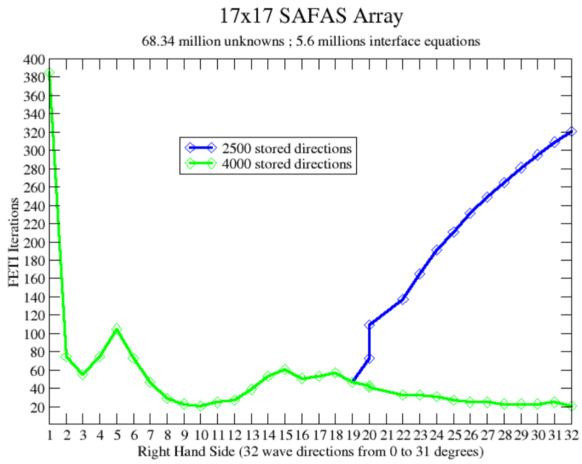

Fig. 3. FETI iterations with the initial projection strategy; 32 incidences

3. Conclusion

In this article a new way of using Krylov type iterative algorithms is proposed in order to improve the FETI-2LM domain decomposition method for solving multi-source electromagnetic problems. Speed-up of 20 is observed with the block Krylov recycling strategy.

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