Solving large electromagnetic problems in small computers

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1. Introduction
The aim of this paper is to review our activity in the last years in order to develop and/or implement efficient algorithms for the solution of large electromagnetic problems. We will restrict our attention to 3D integral equations formulation discretized by Method of Moments (MoM) [1], Rao, Wilton and Glisson (RWG) basis functions [2] and Generalized Minimum Residual (GMRES) [3] iterative solution.

2. The Integral Equation
MEI (IE-MEI)
A sparse matrix integral equation formulation was developed. The results for TM and TE 2D problems [4][5] are excellent (Fig. 1), but the object must be of convex shape to avoid full sub-matrices [6]. The implementation in 3D with RWG is neither accurate nor efficient [7].

Fig. 1: Monostatic RCS of a 2D ogival cylinder, TM polarization, IE-MEI compared with Geometrical Optics (GO) and Geometrical Theory of Diffraction (GTD) high frequency approximation. The number of pulse basis functions (and unknowns) is 51,200. Computation was done in 1996 in a Pentium 133 MHz in 10.7 sec. for computing IE-MEI coefficients with frequency extrapolation and 2.6 sec. per incidence direction to compute the induced current. The memory used to store matrices was 9.42 MB.
3. Multilevel Matrix Decomposition Algorithm (MLMDA)

The 2D MLMDA [8] was extended to 3D problems [9]. MLMDA in 3D is very efficient to analyze planar or piece-wise planar objects with any Green’s function. For example, the results for microstrip antennas are excellent [10] (Fig. 2) and the computation time is comparable to free-space implementation of MLFMA for the same accuracy.

Fig. 2: Induced current in a 16x16 microstrip array, of size $14\lambda \times 11.5\lambda$. A coarse discretization of multilayer MPIE with 27,720 RWG basis functions was analyzed by MLMDA and ILU preconditioning in 13 min., and a fine mesh discretization with 58,884 unknowns in 56 min., without using symmetries or redundancies, in a PC computer with AMD Athlon CPU at 1.33 GHz and 1.5 GB of RAM.

4. Multilevel Fast Multipole Algorithm (MLFMA)

The MLMFA [11] is possibly the most efficient algorithm for accelerating the MoM solution of general 3D electromagnetic problems with arbitrary surfaces. Previous research in MLFMA, ref. [11], addresses scattering computations with the well-conditioned CFIE. We have concentrated our efforts in the computation of antenna radiation.

Fig. 3: Aperture field and current distribution in a X-band horn. The discretization of EFIE with 69,000 RWG basis functions was solved by the MLFMA with ILU preconditioning in 55 min., in a PC computer with AMD Athlon CPU at 1.0 GHz and 1.5 MB of RAM.
with EFIE, which is ill-conditioned for very large numbers of unknowns and requires the use of large preconditioners. Fig 3. shows an example of educational interest for our Antenna Theory courses.

5. **Block-ILU preconditioner**

When the preconditioner required for the iterative solution of EFIE with MLMFA and GMRES is too large to fit in-core RAM memory of the computer, one cannot efficiently do the conventional ILU decomposition of the preconditioner [3]. In order to remove this bottleneck, we have developed a block-ILU algorithm [12] that allows the use of huge preconditioners (Fig. 4).

![Block-ILU Algorithm](image)

Fig. 4: Radiation pattern of the unshielded TARA antenna. The diameter is 33λ and the reflector, feeder, and supporting struts have been modeled with 479,200 RWG basis functions. The EFIE was solved with a 40-block ILU preconditioner and MLFMA in 65 hours in a PC computer with AMD Athlon CPU at 1.0 GHz and 1.5 MB of RAM.

6. **Algorithm optimization for fractal antennas**

The above algorithms can be optimized for structures defined by an Iterated Function System [13], like most fractal antennas, as shown in Table I.

<table>
<thead>
<tr>
<th>Sierpinski iterations</th>
<th>MoM direct</th>
<th>MoM+GMRES+MLMDA+IFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory (MB)</td>
<td>Time (sec)</td>
<td>Memory (MB)</td>
</tr>
<tr>
<td>6 it., N=5,104</td>
<td>397.5</td>
<td>559</td>
</tr>
<tr>
<td>7 it. N=15,310</td>
<td>3577.5</td>
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</tr>
</tbody>
</table>

Table I: Computer requirements for the simulation of 6 and 7 iteration Sierpinski antennas at 9 GHz. The number of unknowns is respectively 5,104 and 15,310. Conventional MoM + direct matrix inversion is compared with MoM + GMRES iterative solution + preconditioning + Multilevel Matrix Decomposition Algorithm (MLMDA) + exploiting IFS structure redundancies [13].
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References


