Fast and Memory-Efficient Method for Full-Wave Analysis of Electrically Large Reflector Antennas and Satellite Platforms

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Abstract – **We present a method that enables full-wave analysis of electrically large antennas and platforms, e.g., a detailed telecommunication satellite at Ka-band. Owing to the efficient formulation, even large problems can be solved on relatively modest computing platforms such as laptops or off-the-shelf workstations. The method is based on the higher-order Method of Moments, accelerated by Multi-Level Fast Multipole scheme and further augmented by several techniques published in the last two years.**

Index Terms — **Reflector antennas, satellite platforms, higher-order Method of Moments, Fast multipole method.**

1. Introduction

Telecommunication satellites typically employ a large number of antennas accommodated in close proximity of each other, due to the limited space available. This necessitates a detailed and accurate RF analysis of each antenna in its final operating environment, i.e., by taking into account the presence of other antennas as well as the satellite platform. A full-wave method offering very accurate results is needed to remove uncertainty and reduce the risks. However, the electrical size of the platform typically prevents an accurate analysis without resorting to special computer hardware, e.g., a large computing cluster.

We present an efficient and accurate full-wave method that enables analysis of entire satellite platforms, including antennas and solar panels, using just off-the-shelf hardware, e.g., a computer with 2 CPU sockets. The method is based on the higher-order Method of Moments (MoM) [1] that was recently accelerated with a higher-order Multilevel Fast Multipole Method (HO MLFMM) [2]. The method is further improved by adding support for non-connected meshes by means of a discontinuous Galerkin formulation [3], that has been extended to work with higher-order basis functions and meshes. The use of out-of-core techniques allows the memory footprint to be further reduced if needed, while a block GMRES is incorporated to accelerate the computation of multimode waveguide scattering matrices of feed horns [4]. Finally, the evaluation of the radiated field is realized using a recently introduced method for fast current integration, which allows strict error-control, even for observation points in close proximity of the source distribution [5]. The efficiency and accuracy of the combined method are demonstrated with a detailed RF model of a telecommunication satellite at C, Ku, and Ka-bands.

2. Description of the Algorithm

Integral equation solvers for electrically large structures are typically based on a surface discretization with associated current basis functions. Most commercial solvers employ RWG basis functions, but these functions require a relatively large number of unknowns to achieve the desired accuracy. In contrast, higher-order basis functions and large curved patched reduce the number of unknowns by approximately a factor of 5 [1]. Due to the large patches, traditional MLFMM schemes cannot work efficiently with higher-order basis functions. Recently, a new scheme was introduced that allows very high expansion orders to be used, while maintaining a low memory consumption [2]. At the same time, the CPU time is dramatically reduced. The solver we present here is also the first solver to use both higher-order basis functions and a discontinuous Galerkin approach [3]. The resulting algorithm allows non-connected meshes without compromising the accuracy or the iteration count, while making CAD cleaning and model preparation significantly easier and more robust. This is illustrated in Fig. 1, that shows the surface currents flowing continuously on a complex structure represented by a non-connected mesh.

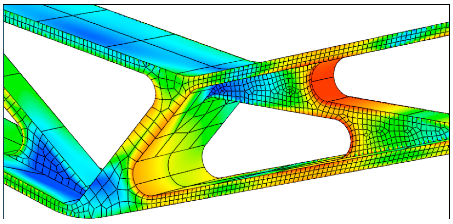

Fig. 1. Currents flowing continuously on a non-connected mesh, analysed by HO MLFMM and the discontinuous Galerkin approach.

The HO MLFMM approach has been shown to be very suitable for an out-of-core implementation [4], because the largest part of the memory is occupied by data structures that are only used once per iteration. This allows the solver to automatically reduce the peak memory consumption by using disk storage instead of RAM. Even large problems, e.g., ESA's Planck space telescope (166,000 λ^2) can then be solved on a laptop [4]. This reference also describes a block GMRES solver, which has been incorporated to reduce the iteration count when solving coupled problems for extraction of waveguide scattering matrices.

The HO MLFMM algorithm reduces the workload needed to compute the currents. However, the subsequent field evaluation quickly becomes the bottleneck unless a fast method is used for integration of surface currents. We use the accelerated method proposed in [5], which allows strict error bounds to be imposed on the field evaluation, even for observation points in the extreme near field. This technique reduces the frequency scaling of the computation such that the time spent on field computations is usually negligible.

3. Application Example

We consider a full-size detailed model of a typical telecommunication satellite operating at C, Ku, and Ka-bands. For simplicity, we consider the frequencies 10 GHz, 20 GHz, and 30 GHz. A drawing of the satellite and the dimensions are shown in Fig. 2 below. A small part of the mesh is shown in Fig. 3. The large electrical size is reflected in the very dense mesh, despite the fact that each curvilinear mesh element is roughly 1.5 x 1.5 wavelengths.

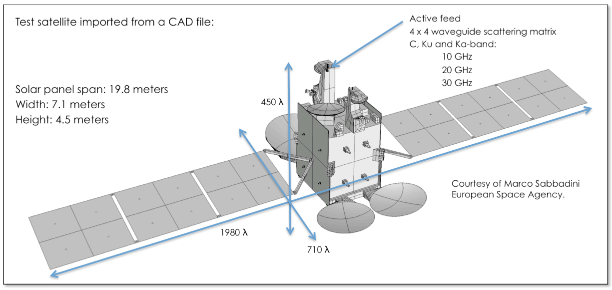

Fig. 2. Schematic drawing of typical telecommunication satellite, including the electrical size at 30 GHz. (CAD model credits: Marco Sabbadini, European Space Agency).

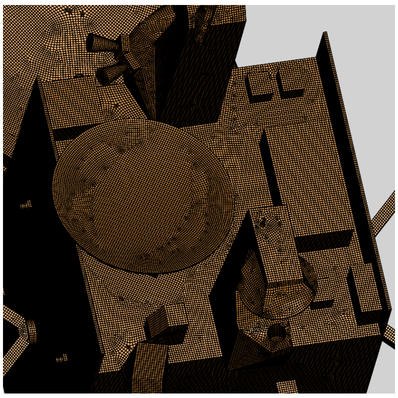

Fig. 3. Close-up of the mesh of the earth deck of the satellite. The dominant patch size is 1.5 x 1.5 wavelengths.

The active antenna is located on the earth deck and we report the CPU time needed to compute the currents for a single excitation, as well as the time needed for computation of a 4x4 scattering matrix, corresponding to the first few propagating waveguide modes in the feed horn. Note that this computation requires the solution for four different excitations. The out-of-core features of the solver are not used for this example since sufficient RAM is available. The computations are performed on a dual Xeon @ 2.6 GHz and Table I shows the number of higher-order unknowns, the equivalent number of RWG unknowns, as well as the computational resources needed to solve the problem. The data are reported for 10, 20, and 30 GHz, thereby covering the typical communication bands used today.

TABLE I
Resources needed for full-wave solution of satellite

	10 GHz	**20 GHz**	**30 GHz**
Electrical size	116,447 λ^2	465,792 λ^2	1,048,031 λ^2
HO Unknowns	2,120,171	8,175,034	18,166,143
Equi. RWG unkn.	10,000,000	40,000,000	90,000,000
Iterations	46	82	94
Time, 1 excitation	0:44 hrs	3:15 hrs	7:12 hrs
Time, 4x4 S-matrix	2:21 hrs	9:21 hrs	22:55 hrs
Memory	65 GB	227 GB	380 GB

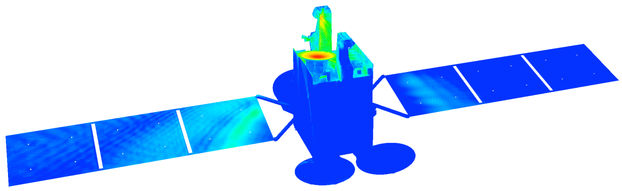

Fig. 5. Currents on the satellite computed at 30 GHz.

4. Conclusions

We have presented a fast and memory-efficient method for full-wave analysis of electrically large antennas and platforms. The method allows a full-size detailed model of a telecommunication satellite to be analysed in C, Ku, and Ka-bands. The runtime is in the order of a few hours on a standard dual Xeon computer, thus indicating that electrically very large problems can be accurately solved without the need for special hardware, such as computing clusters. The method allows accurate computation of antenna coupling and interference, including waveguide scattering matrices. Additional results will be shown at the symposium to illustrate the convergence rate of the method while at the same time demonstrating that high accuracy is significantly cheaper to obtain with the present high-order approach, compared to the commonly used low-order methods.

References

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