Fast Source Reconstruction of Large Reflector Antennas for Space Applications

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***Abstract*—In this work, a method for diagnostics of large reflector antennas for space applications is presented. By using a Calderón projection together with a Higher-Order (HO) Method of Moments (MoM) discretization, the inverse electromagnetic scattering problem is solved in an efficient manner, allowing for diagnostics based on the equivalent currents. This method is referred to as the Calderón method and is shown to be well suited for use in antenna diagnostics applications. Two reflector antenna cases have been analysed and significant reductions in computation time and memory allocation requirements are observed in comparison to other state-of-the-art solvers.**

I. Introduction

The rapid advancement of antenna applications at millimetre wave frequencies in recent years has increased requirements for simulation tools to be able to analyse electrically large and complex antennas. Further, by virtue of the added complexity of the antennas, practically all designs must be verified experimentally before being deemed fit for operation. This development has increased the need for fast antenna diagnostics solvers that can be used to identify the source behind performance reductions encountered in fabricated antennas. A successful method for this purpose is the equivalent current reconstruction technique. It consists of reconstructing equivalent electric and magnetic currents on an enclosing surface close to the antenna under test (AUT). Visual inspection of the reconstructed currents can then be used to locate the source of performance deviations of the AUT.

The equivalent current reconstruction technique has been implemented numerically in many different incarnations, but the most accurate class of methods is known as full-wave inverse electromagnetic solvers. The asymptotic scaling of full-wave inverse solvers implies that using these methods for source reconstruction on electrically large scatterers has previously been extremely costly in terms of random access memory (RAM) allocation and computation time. However, recent numerical advances of the formulation and solution scheme of the inverse electromagnetic problem have paved the way for running antenna diagnostics on larger an more complicated structures than previously possible [2]–[4].

In this work, the accelerated inverse Method of Moments (MoM) solver presented in [4] is used to perform source reconstruction antenna diagnostics on large reflector antennas for space applications. By reconstructing equivalent electric and magnetic currents on an enclosing surface close to the reflector, conclusions are made on the source of performance deviations of the antenna in relation to an nominal design. We show that without the strong numerical implementation in the present paper, it would be practically impossible to solve problems of the electrical size shown here on standard computational machines. Details on the numerical implementation of the new method, and how it differs from previous inverse solvers, are given in [4].

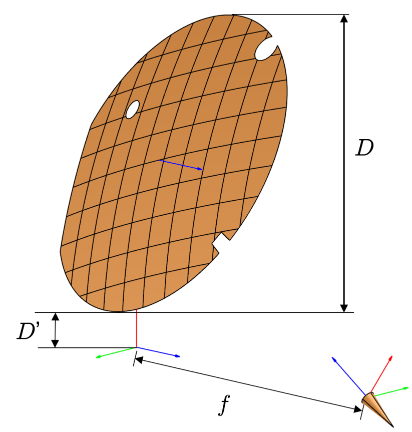

Fig. 1. Geometry of offset reflector antenna designed in TICRA Tools ESTEAM.

II. Results

Two offset reflector antennas operating at 12 GHz have been designed in TICRA Tools ESTEAM [5]. The first reflector antenna has a diameter (D) of 1.6 m, a focal length (f) of 1.6 and a clearance (D') of 0.2 m. The electrical size of the reflector is 64 wavelengths, and the f/D-ratio is 1.0. The reflector is illuminated by a Gaussian feed with a tapering of -12 dB at the rim of the reflector, and the antenna geometry is presented in Fig. 1. For the practical realisation of a reflector antenna on a spacecraft, it may be necessary to make cut-outs along the rim of the reflector in order to allow space for attachment points or similar. Furthermore, a defect is introduced to the reflector surface in the form of a circular hole with a diameter of 0.1 m. A comparison of the realistic reflector surface with a corresponding ideal surface is presented in Fig. 2.

The reflector antenna was analysed using the multilevel fast multipole method (MLFMM) in TICRA Tools ESTEAM, and the far-field of the antenna was calculated over a full-sphere with a sampling density of 0.2° in θ and ϕ, to simulate the process of measuring the reflector antenna. This simulated data was then processed in MATLAB where a random noise level

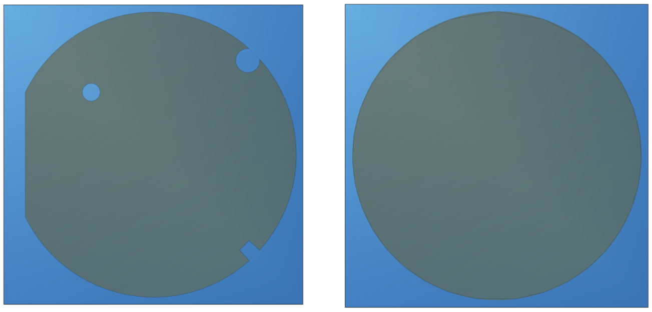

Fig. 2. Reflector antenna geometries enclosed by DIATOOL reconstruction surfaces, modified reflector (left) and reference reflector (right)

corresponding to a signal-to-noise ratio (SNR) of 60 dB was added. This step was carried out to to make the simulated data resemble actual measured data. The advantage of using simulated data instead of real measured data is that we now have full control of the noise level in the data, which means that it is possible to evaluate the accuracy of the source reconstruction. The far-field data was then loaded into a development version of the TICRA antenna diagnostics software DIATOOL [5]. A rectangular box reconstruction surface (RS) was defined such that the full reflector was enclosed with a 5 % oversize factor. The Calderón reconstruction method, described in detail in [4], was used for recreating the equivalent currents and fields at the RS. The computational requirements of the current reconstruction operation are presented in Table I.

The first reflector case consists of 478 200 higher-order (HO) unknowns. It requires 7 GB of random access memory (RAM) and the source reconstruction finishes in 30 minutes on a 24-core workstation computer. The same analysis carried out with the standard form conjugate gradient least-squares (SCGLS) method, the state-of-the-art solver in DIATOOL 1.1, requires 9.7 TB of RAM and would take an absurd amount of time to complete. This analysis was not carried out, mainly because the amount of required RAM was not available to the authors of this paper. The amplitude of the reconstructed electric current from the inverse MoM analysis is presented in Fig. 3 according to the expression $20\log_{10}(|\boldsymbol{J}_S^{\mathrm{rec}}|)$. The reflector rim cut-outs and the hole in the surface can easily be identified in the current amplitude in Fig. 3.

The second reflector antenna design that was analysed is a larger scaled version of the first antenna, where the reflector diameter and focal length are both 3.3 m and the clearance is 0.2 m. The electrical size of the reflector is 132 wavelengths and $f/D = 1.0$ also in this design. A process similar to the first reflector, but with sampling distance $0.1°$ in θ and ϕ, was carried out to get the field samples. The computational requirements and specifications are presented in Table I. It is noted that this problem consists of about 2.1 million HO unknowns, requires 27 GB of RAM, and finishes in a bit over 2 h on a workstation computer. Running the same analysis with the SCGLS method would require a prohibitive 176 TB of RAM.

The reconstructed currents were compared to the currents

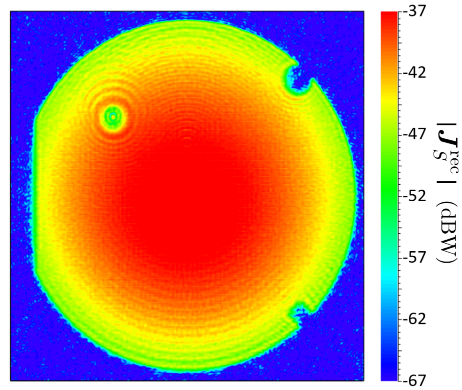

Fig. 3. Amplitude of reconstructed electric current density $\boldsymbol{J}_S^{\mathrm{rec}}$ presented in dB for the case of a medium sized reflector with cut-outs.

TABLE I
ANALYSIS REQUIREMENTS OF TWO REFLECTOR ANTENNA SOURCE RECONSTRUCTION CASES EVALUATED WITH DIFFERENT METHODS.

Reflector size	Solver	Nbr. of unknowns	Memory req. [GB]	Comp. time [hh:mm]
Medium	Calderón	478 200	7	00:30
Medium	SCGLS	478 200	9 710	–:–
Large	Calderón	2 070 200	27	02:14
Large	SCGLS	2 070 200	175 921	–:–

of the forward MoM computations in ESTEAM and from this the root-mean-square (RMS) error was computed between the two datasets. The worst-case current error in the medium size reflector case is 7.0 % and the corresponding error in the large reflector case is 10.7 %. It is concluded that the achieved error levels are sufficient for antenna diagnostics applications.

III. Conclusion

Source reconstruction of large reflector antennas for space applications has been presented, demonstrating a drastic reduction in memory and increase in computational speed over previous methods. The presented method is based on the Calderón inverse MoM solver developed by [2] and efficiently implemented in [4]. The results clearly display the extreme acceleration that the new method provides in relation to other MoM-based source reconstruction algorithms with no significant reduction of accuracy.

References

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