Efficient Integral Equation Based Solvers for Modelling Antennas Mounted on Electrically Large and Complex Platform

(Invited Paper)

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***Abstract*— Efficient modelling of the performance of antennas mounted on electrically large and complex platform is essential for practical antenna design with considering environment effect and yet a challenging area in electromagnetic compatibility (EMC) assessment. This paper presents our team efforts to tackle this problem through three ways: (1) fast full-wave simulation code development with technical core of surface-wire integral equation (SWIE) and precorrected-FFT (P-FFT) algorithm; (2) efficient hybrid low and high frequency modelling capability with technical core of a newly developed efficient iterative method of moments (MoM) – physical optics (PO) hybrid method; (3) hardware accelerated simulation capability with technical core of parallel P-FFT implementation for solving SWIE on GPU. Successful simulation of many standard benchmarks and realistic targets extensively validates the proposed three techniques.**

I. INTRODUCTION

Efficient modelling and characterization of the behaviour of antennas mounted on electrically large and complex platforms remains a challenging research topic in the area of electromagnetic compatibility (EMC) assessment. Full-wave solution obtained through the method of moments (MoM) [1] is accurate for understanding the physical phenomena of antennas mounted on platform and it is usually limited to electrically small problems due to the requirement of large computational memory resources. High frequency techniques were developed [2], [3] to model the antennas behaviour mounted on large platforms with certain assumptions. How to verify and improve the accuracy of the high frequency techniques through careful comparison with the accurate full-wave solution is also one of the key issues for developing the high frequency techniques.

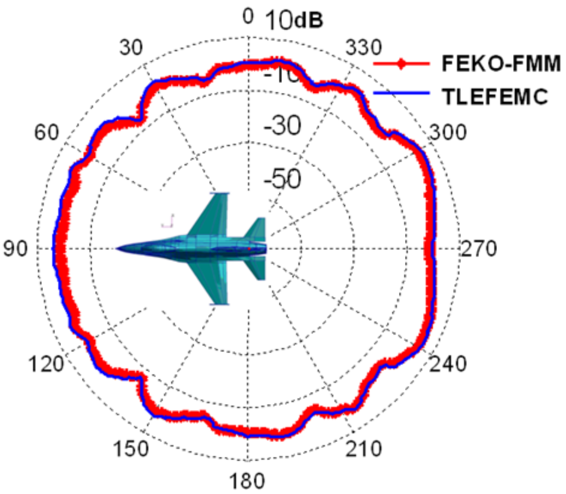
To tackle this challenging problem, three efficient ways have been developed for accurate modelling of antennas mounted on practical platform: (1) fast full-wave simulation code development with technical core of surface-wire integral equation (SWIE) and precorrected-FFT (P-FFT) algorithm; (2) efficient hybrid low and high frequency modelling capability with technical core of a newly developed efficient iterative method of moments (MoM) – physical optics (PO) hybrid method; (3) hardware accelerated simulation code with technical core of parallel P-FFT implementation for solving SWIE on GPU.

II. FAST FULL-WAVE SIMULATION

For the fast full-wave simulation development, the SWIE is adopted to characterize the currents on the surfaces of the platform, wire antennas, and wire-surface junctions. The current on the surfaces of platform is expressed using RWG basis functions [1] defined on the triangle mesh, and the current on the wire antenna is expressed using triangle basis functions defined on the wire mesh. The other important current component is derived from the wire-surface junction, which affects the accuracy of the antenna impedance. In order to accurately model this current component, a well defined junction basis function must be applied to the proper mesh of the surface-wire junction [4]-[8].

With all these basis functions, the SWIE can be discretized into a matrix equation **ZI=V** through following standard MoM procedure. This matrix equation can be efficiently solved using the GMRES iterative solver with the help of the P-FFT algorithm [7]-[11] with the ILU preconditioner [12].

This method has been implemented into an efficient code [8], namely the Temasek Laboratories (TL) efficient full-wave EMC (TLEFEMC V1.0) code [13]. The code has been extensively validated and its application to realistic targets illustrates its capability. With this code, we can simulate EMC problem of some realistic air platform up to the frequency of 1.0 GHz using one AMD 2.6 GHz Processor on Opteron Machine. The solution obtained using the TLEFEMC V1.0 code can also be a good benchmark for high frequency techniques. Fig. 1 shows the simulated directive gain a monopole mounted on stabilizer of a generic airplane model of 13 meters long at 600 MHz with comparison with the results simulated using FEKO. Very good agreement between the results obtained using our code and FEKO validates accuracy and efficient of the code.



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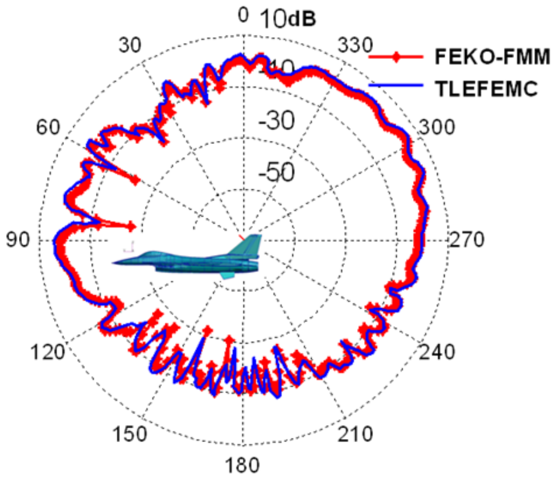

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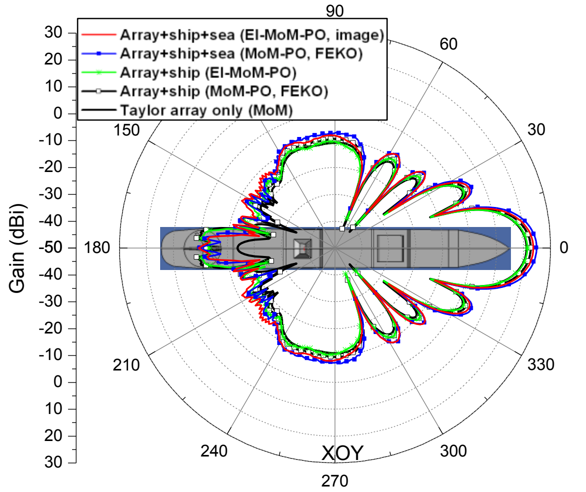
Fig. 1. Total directive gain patterns of monopole mounted on a generic airplane model.

III. Efficient Hybrid Low and High Frequency Modelling

The fast full-wave technique is accurate, but it usually takes long time to predict antenna performance with considering effect from electrically large platform. In order to reduce CPU time for modelling large system, an efficient hybrid low and high frequency technique, namely efficient iterative method of moments (MoM) – physical optics (PO) (EI-MoM-PO) method, is proposed for the problems of onboard antenna with electrically large complex platform [14]. The EI-MoM-PO method does not couple the PO contribution into the MoM impedance matrix, and the PO contribution is considered as the additional voltage source of the MoM-region instead. Then an iterative process is efficiently implemented between MoM-region and PO-region until the error of the MoM current is smaller than a prescribed threshold. This technique shows much better efficiency and maintains the same accuracy with same number of unknowns compared with the conventional MoM-PO method [14]. Therefore, the EI-MoM-PO method is very suitable for analysis of the onboard wire antenna array with large-scale platform.

Fig. 2 shows simulated gain patterns of a Taylor dipole array mounted on ship platform of length 152 meters at 1.0 GHz. The EI-MoM-PO method is more than 20 times faster than FEKO MoM-PO solver.



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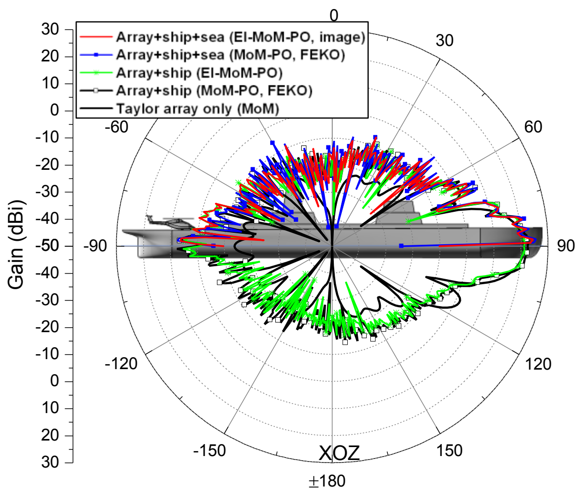

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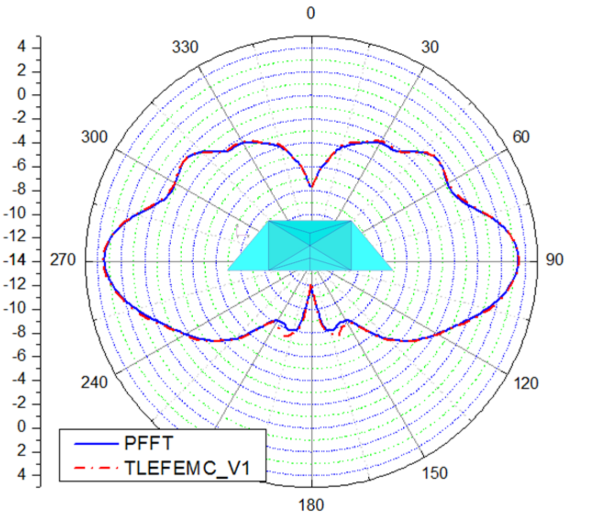
Fig. 2. Directive gain patterns of a Taylor dipole array mounted on ship platform.

IV. GPU Hardware Accelerated Modelling

In addition to developing efficient algorithms for modelling installed antenna performance with considering platform effects, we also develop hardware accelerated technique to further speed up our developed fast algorithms through fully taking advantages of the state-of-the-art evolution of graphics processing unit (GPU).

In the computing process, CPU handles the job control, which it is good at. CPU also deals with the all the pre-processing work such as initialization, projection and near-zone element computation. Even the iteration process is conducted on CPU. Only when matrix-vector multiplication is needed, GPU jumps in and takes over the job. After going through all the standard routines of P-FFT, GPU returns control to CPU. After the convergence of iteration, CPU continues the followed post-processing. Note that the pre-computed items are copied to and stored in GPU memory to avoid repeated computation, including projection, near-zone items, pre-corrected items. So the size of GPU memory is critical for large problems. In the iteration process, there is also repeated data-exchange between host and device, which makes the program both computation-intensive and bandwidth-intensive.



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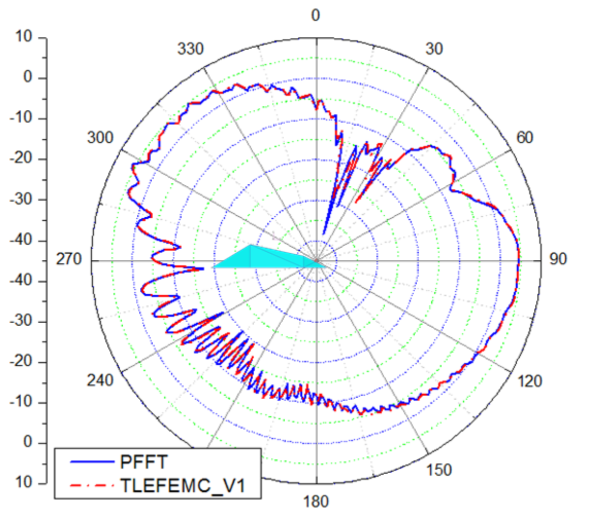

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Fig. 3. Total directive gain patterns of monopole mounted on multiplate structure.

To implement the process of projection, transition, interpolating and adding near-zone items on GPU, we write separate routines using CUDA, called Kernel. In the iteration, GPU launches the kernel on the data we copied from host with thousands of cores concurrently. Details of the implementation of each kernel function can be found in [15]. For FFT transform, there are existing GPU FFT libraries. In our program, the CUFFT library provided in CUDA is used, which is fast, stable and widely used.

It is worthy of note that the performance of GPU code depends on many fine tunings. Different implementation and parameters can result in great performance difference. Thus, as a general rule, more focus should be placed on how to optimize the GPU code to fully exploit the specific features of GPU to achieve better performance, especially for advanced and complex algorithms [15].

Based on the proposed parallel algorithm, we have applied the code to the analysis of radiation patterns of a monopole mounted on a multiplate structure and the stabilizer of a plane. The test shows not only good accuracy but also much faster computational time on GPU. Fig. 3 shows the directive patterns of monopole mounted on a multiplate structure [13] at 4 GHz. The GPU acceleration ratio is about 16.

V. Conclusion

Fast full-wave (TLEFEMC V1.0) code is accurate and capable of modeling antenna mounted on real platform up to certain frequency. It is also a robust solver for benchmarking high frequency method based solver. Hybrid method EI-MoM-PO method is able to efficiently model antenna mounted on large platform with providing design capability for real application. GPU hardware accelerated modeling technique for fast full-wave technique provides another way to speed up algorithms for achieving better performance for real design. The proposed mapping process with efficient optimization scheme can also be a good guidance for mapping other FFT-based fast algorithms [16]-[21]. More results and discussion will be presented at the conference.

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