GPU-Acceleration of Characteristic Basis Function Method (CBFM) for Efficient Analysis of Complex Platforms involving Layered Media

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***Abstract*—In this paper, we present a scheme for efficient numerical modeling of operating at millimeter wavelength, e.g., 30 GHz. One of the key features of the method is the GPU acceleration adapted for the Characteristic Basis Function Method (CBFM) acceleration for problems involving layered media, which to the best of our knowledge has not been done in the past.**

Keywords—Characteristic Basis Function Method (CBFM), GPU acceleration, layered media

I. INTRODUCTION

Mobile devices for 5G operate at millimeter wavelength, e.g., 30GHz; hence, the problem size becomes very large as compared to those operating below 5GHz. To handle the issue of large and burdensome CPU time and memory requirements, and to render the problem manageable, we propose several strategies to accelerate the analysis, including geometry simplification, application of a numerical algorithm for memory reduction, and GPU acceleration. The memory reduction is primarily achieved by employing an efficient iteration-free technique, the Characteristic Basis Functions Method (CBFM) proposed in [1], and has been extensively investigated by a number of authors, including [2], to analyze objects embedded in multi-layered media.

To illustrate the performance enhancement techniques for numerical solution, we choose the geometry of a mobile device (see Fig.1) comprising of a metallic frame and an antenna located on a layered medium space(see Fig.2). Our first step is to simplify the geometry, without compromising the electrical performance, which enables us to significantly reduce the number of unknowns from 99738 (original) to 1892 (reduced) at a frequency of 30GHz. Next, we modify the existing CBFM algorithm, previously designed for scattering problems, and adapt it for the layered media case by using two different types of sources as excitations to generate the Characteristic Basis Functions (CBFs) in the context of the antenna problem at hand [3]. It has been well established that the CBFM enables us to significantly reduce the size of the associated matrix in comparison to that of the conventional MOM, and this is true regardless of the type of excitation used, and we find that the Edge-Port-provided CBFM perform the best. This is because the near-field contents of the Edge Port (EP) and Dipole Moment (DM) excitations both contain the invisible range of the spectrum, which the traditional plane wave excitations do not and this in turn, contributes to the enhancement of the accuracy in the EP and DM approaches. The GPU acceleration, which plays a key role, speeds up the filling process of the submatrices of the impedance matrix when we generate the Characteristic Basis Functions (CBFs).

II. CBFM FOR MICROWAVE CIRCUIT AND ANTENNA PROBLEMS

Based on the mixed-potential integral equation (MPIE), the CBFs are constructed from low-level basis functions, namely RWGs. For each level of CBFs, we can express the reduced matrix equation as follows:

$$\left[\boldsymbol{Z}^{l}\right]_{\sum_{i}^{B_l} K_{l,i} \times \sum_{i}^{B_l} K_{l,i}} \left[\boldsymbol{I}^{l}(\theta,\phi)\right]_{\sum_{i}^{B_l} K_{l,i} \times 1} = \left[\boldsymbol{V}^{l}(\theta,\phi)\right]_{\sum_{i}^{B_l} K_{l,i} \times 1} \tag{1}$$

where $\boldsymbol{Z}^l$, $\boldsymbol{I}^l$, and $\boldsymbol{V}^l$ are the l-level reduced impedance matrix, current distribution coefficients vector and excitation vector, respectively. When $l = 0$ the reduced matrix equation becomes the original MOM matrix equation.

To adjust the CBFM to the problems of millimeter-microwave circuits and antennas, we employ the edge ports on the surface of the object to be analyzed (see Fig.3). This is the most natural approach to fill the excitation matrix when dealing with microwave circuit and antenna problems, as opposed to scattering problems, which uses plane waves. To generate the CBFs for an antenna geometry, the edge ports is used for filling the excitation matrix. In this case, the geometry of the dipole is partitioned into 4 blocks, the dark blue faces denote the extended region, and the red lines denote the edge ports whose orientation is set along the x-axis. Besides, in an antenna application, if we use a single delta-gap source for the excitation, then this source, which is implemented as an edge port, should be considered as one of the sources used to fill the excitation vector.

An alternative approach is to use an excitation source which is neither the far-field type, as for instance a plane wave, nor is located on the body (shown in Fig.4), as was the case with the edge-port excitation. For this case, we choose the dipole moments as the sources in the vicinity of the object to generate the excitation matrix, thereby introducing both the near-field and far-field information into the construction of the CBFs.

III. NUMERICAL RESULTS

We now demonstrate the accuracy and efficiency of the CBFM applied antenna problem, as well as the effectiveness of GPU acceleration. A PEC dipole in free space is used for the first example (see Fig.5). When implementing the CBFM, the dipole is partitioned into 4 blocks, along the direction of its length, and a delta gap port is used for the excitation at the center. The frequency ranges from 300MHz to 700MHz, with a step of 50MHz. A total of 324 triangular elements are used to discretize the antenna, and the lengths of the elements are 0.1-wavelength at 500MHz. To construct the CBFs, an extension of 0.1 wavelength of 500MHz is used. The Z11 results are plotted in Fig.6, where the results calculated by the conventional MOM are used as the reference. In this example, the thresholds of the SVD down-selection, and the number of samples and unknowns of the reduced matrices, are shown in the Table I, where EP denotes the edge-port, PW denotes the plane-wave and DM denotes the dipole-moment excitation, respectively.

In the second example, we analyze a PEC cross (see Fig.7) laying on the interface of layered medium, to illustrate the acceleration achieved by the GPU. The length and width of each arm are 10 wavelengths and 2 wavelengths, respectively. The layered medium is backed by a PEC, the frequency is 30 GHz, and the number of unknowns is 12085. The fill-time for the matrix is shown in Table II, where we demonstrate that the use of the GPU significantly accelerates the computation. The versions of GPU and CPU are Nvidia GTX860M and Intel I7-4710HQ, respectively. The memory storage is 8 GB and the numerical results of CPU is calculated using a commercial software.

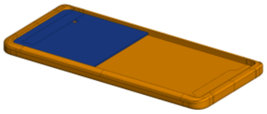

Fig.1. Original cellphone

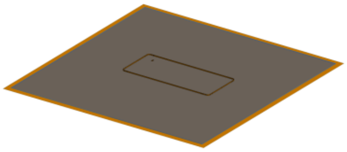

Fig.2. Simplified Full-size cellphone

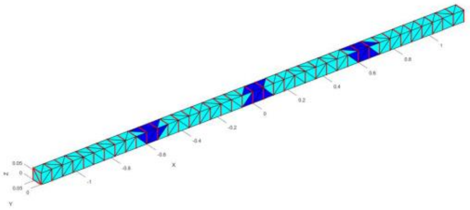

Fig.3. Edge ports on a dipole

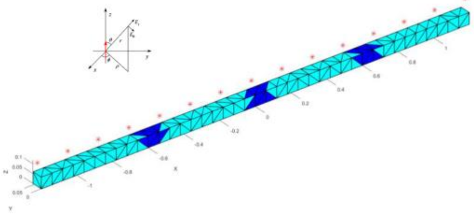

Fig.4. Dipole moments above a dipole

Fig.5. PEC Dipole

TABLE III. PARAMETERS AND RESULTS OF EXAMPLE 1

Method	threshold	samples	Min(unknowns)	Max(unknowns)
EP-CBFM	0	96	96	96
PW-CBFM	1e-3	400	110	184
DM-CBFM	0	120	120	120
MOM	0	0	486	486

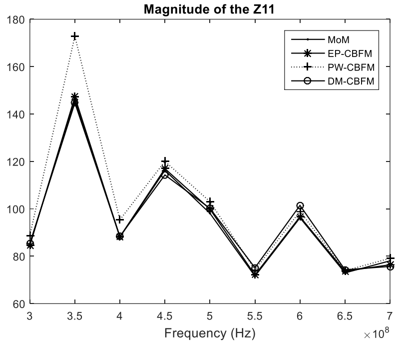

Fig.6. Z11 of Example-1 obtained by Using CBFM

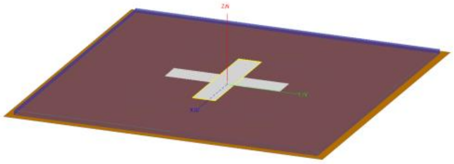

Fig.7. PEC cross embedded in layered medium

TABLE II. TIME USED FOR MATRIX FILLING ON DIFFERENT PLATFORMS

Platform	**Matrix Filling Time**
GPU	0.7 min
1 CPU-Core	26.6 min
2 CPU-Core	20.0 min
4 CPU-Core	24.0 min
6 CPU-Core	26.4 min
8 CPU-Core	26.5 min

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