Improving a time domain spherical multipole near-to-far-field transformation algorithm

Glaucio L. Ramos[1,4], Cássio G. Rego[2], Alexandre R. Fonseca[3].
[1]Department of Telecommunications and Mechatronics Engineering, Federal University of São João del-Rei, Brazil
[2]Department of Electronic Engineering, Federal University of Minas Gerais, Brazil
[3]Computer Department, Federal University of Vales do Jequitinhonha e Mucuri, Brazil
[4]Graduate Program in Electrical Engineering - Federal University of Minas Gerais, Brazil
glopesr@gmail.com, cassio@cpdee.ufmg.br, arfonseca@ufvjm.edu.br

***Abstract*—A time domain spherical multipole near-to-far-field algorithm running in a parallelized code version is introduced in this paper. Such approach is employed to obtain UWB antenna radiated fields and radiation patterns directly in time-domain, which is more convenient to perform an unified characterization in time and frequency domains. We propose the use of the OpenMP, an Application Program Interface that permits the code parallelization with almost no intervention. Results show that the proposed technique allows a code running 28 times faster when using a computer with 24 processors, each one with 2 threads, when compared to the sequential one.**

***Index Terms*—Time domain spherical multipole expansion, parallel processing, OpenMP, UWB antenna characterization.**

I. Introduction

The near-field components, which can be calculated by a FDTD solver, over a Huygens surface can be replaced by equivalent electric and magnetic dipoles, and the far field generated by a UWB antenna can be obtained in the time domain by a near-to-far-field transformation and expressed as [1], [2]

$$\vec{e}_\infty(\vec{r},t) = -\sum_{n,m} a_{n,m}\left(t-\frac{r}{v_c}\right)\vec{n}_{n,m}(\theta,\phi) + Z_0\sum_{n,m} b_{n,m}\left(t-\frac{r}{v_c}\right)\vec{m}_{n,m}(\theta,\phi), \quad (1)$$

where Z_0 and $v_c = 1/\sqrt{\mu_0\varepsilon_0}$ are, respectively, the intrinsic impedance and the velocity of light in vacuum, $\vec{n}_{n,m}(\theta,\phi)$ and $\vec{m}_{n,m}(\theta,\phi)$ are the set of vector functions with respect to the transverse fields on a spherical surface and $a_{n,m}(t)$ and $b_{n,m}(t)$ are the electric and magnetic time-domain spherical-multipole amplitudes.

The main advantage of time domain multipole approach is that the radiated fields can be obtained for an antenna excited by any sources with pulsed temporal behavior and thus it allows the characterization of its radiation pattern in time and frequency domains. Such approach is very useful on performing an unified characterization of UWB antennas. The representation expressed in Eq. (1) is not based on the retarded potentials, which eliminates the need of source integration for each observation point. Such feature makes this technique interesting when compared with traditional ones. However, it has the issue of involving a high computational burden due to the process of an intrinsec time convolution [2].

II. Parallel version of the Time-Domain Spherical-Multipole Code

An analysis of the approach developed in [2] shows that each set of multipoles $a_{n,m}(t)$ and $b_{n,m}(t)$ within the same time interval could be independently calculated. Thus an alternative to speed up the calculation of these multipoles amplitudes is the use of a parallel processing technique, which has been widely used on speeding up several electromagnetic solver techniques [3]-[6]. Adopting such parallel process technique the multipole computation can be divided into n threads of execution. Among the alternatives for constructing parallel implementations we can highlight the OpenMP [7], which is an API (Application Program Interface). The OpenMP directive use a pre-compiler to indicate where the code should be parallelized, allowing parallelization of routines with almost none extra code. We propose herein the allocation of each node in a random manner among the threads [8]. Therefore, the convolutions are randomly allocated through the available threads and the usage time of each processor is almost equalized and the time-domain spherical multipole near-to-far-field transformation can be implemented in a more efficient way.

III. Results and Comments

The code parallelization was applied to calculate the vertical radiation pattern of a half wavelength dipole at a frequency of 10 GHz. It was used a computer equipped with an Intel(R) Xeon(R) CPU E7530@1.87GHz processor, with 128 GB RAM and 24 cores, each core with 2 threads, with a total of 48 threads. Results obtained for time and frequency-domain radiation patterns are shown at Fig. 1 and we can see a good agreement between the proposed parallel technique and the analytical solution [9], validating the spherical multipole expansion parallelized version.

The results of the implementation of the proposed parallel technique on the simulation time can be seen at Fig. 2. It can be observed that the use of the proposed parallel processing technique with up to forty-eight cores permits that the radiation pattern be obtained with a processing time twenty-eight times lower. In Fig. 2 we can observe that the processing gain initially shows a linear behavior and after the use of about six threads this processing gain tends to a value of about twenty-eight times, using the forty-eight threads available. This behavior can be explained by the loading distribution process. As this load distribution is randomly performed, the processing time changes for each iteration, and thus some cores will be used by the processing for a longer time than others. Also for the last iterations it is possible that some cores can be free of iteration when other cores can be still being used to process the last iterations. The computer used for this simulation has a total of 24 cores, each core with two threads. When the process is started with a maximum use of 24 parallel used threads, it is used only a single thread for each core. When the code is processed with the use of 25 to 48 threads, the second thread of each core started to be, causing a decrease in the processing gain.

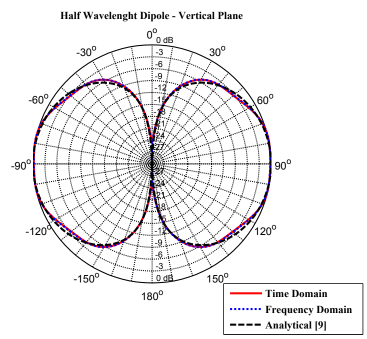

Figure 1: Validation of the parallel code: half wavelength dipole vertical pattern.

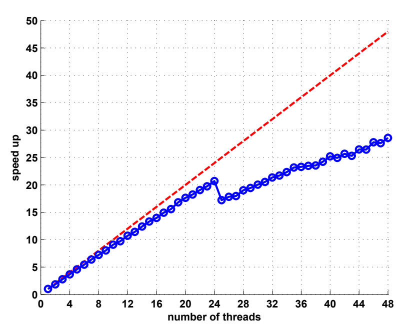

Figure 2: Processing gain of spherical multipole technique with parallelism.

Once the code was validated it was employed to characterize the time and frequency-domain radiation pattern of an UWB antenna [10], as the proposed technique can improve the simulation time of radiation patterns of such antennas. In order to characterize the time domain radiation pattern at different frequencies, a moment expansion technique [11] was applied altogether with the spherical multipole transformation. Once the time-domain far fields were obtained, the antenna transfer function is estimated by the moment expansion and through a convolution process the far field is estimated for a specific frequency. Results for the the radiation pattern of the UWB antenna at 3 and 7 GHz on y-z plane can be seen in Fig. 3. The importance of time-domain radiation patterns relies in the fact that energy and power norms of temporal signals can be used to obtain the antenna radiation patterns for transient and steady-state responses, from any arbitrary source feeding the antenna, which is very important specially for UWB antennas.

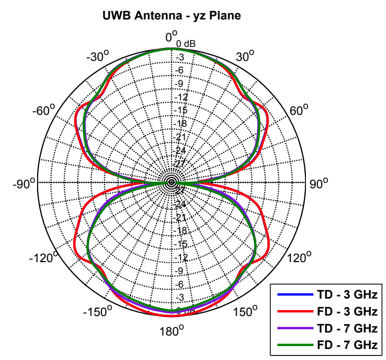

Figure 3: Radiation pattern of an UWB antenna at yz plane.

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