Analysis of Monopole Antenna by FDTD Method Using Beowulf Cluster

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Abstract

As far as we are concerned, the implementation of the Finite Differences in the Time Domain (FDTD) method requires, for the solutions of several practical problems in electromagnetism, a long process time and a large amount of memory, what makes it impracticable in various cases, principally when the serial process is used. The current work deals with the conception of a Beowulf cluster and it aims to implement the FDTD method using parallel process for the study of antennas. The obtained system efficiency is then tested in the analysis of a monopole antenna, what is done by comparing the time spent in the parallel and serial processing.

1. INTRODUCTION

The Finite Differences in the Time Domain (FDTD) method was introduced by Yee, in 1966 [1], and represents a simple and efficient form of solving Maxwell's equations when written in the differential-time domain form. In Yee's proposal, the components of electric and magnetic fields are intercalated in space and time, in such a way that there is reciprocity among them.

In spite of its credibility and precision, the FDTD method has its limits. One of them is the great amount of memory required, and the other one is the long processing time.

A solution for these problems would be the use of more powerful computers, in particular, several processors working at a parallel structure. Another alternative, more financially accessible, would be the use of a technique, developed in the late 80's, that is the cluster architecture of PCs.

In this work, one is using a LAM/MPI library along with the FDTD method to make a precise analysis of monopole antenna and also to show the efficiency of the parallel computation in face to the sequential one.

2. MODELING OF THE ANTENNAS BY FDTD METHOD.

Antenna was analyzed by using the serial and parallel processing. In the two ways of calculations, the space and time discretization were kept the same.

2.1. Cylindrical monopole over a PEC ground plane

The monopole antennas are widely used in wireless mobile communication [1]. Because of their characteristic of broadband and simple building, it is maybe the most common antenna for portable equipment, such as cellular telephones, cordless telephones, automobiles, trains, etc.

The cylindrical monopole antenna shown in Fig.1 represents a two-dimensional electromagnetic problem, because both the antenna and its source of feed are rotationally symmetric.

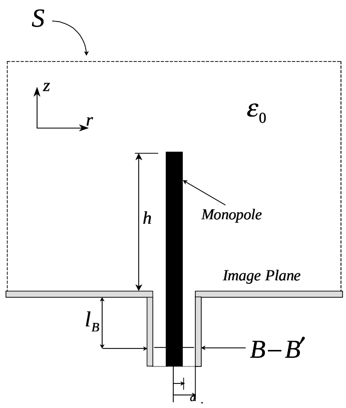

Fig.1. Geometry of the cylindrical monopole antenna

The electromagnetic fields are independent of the angular coordinate (ϕ), and Maxwell's equations may be expressed as two independent groups: One that involves only the components E_r, E_z, H_ϕ, TM mode or transverse magnetic mode; and other that involves only the components E_ϕ, H_r, H_z, TE mode or transverse electric mode [2]. Since the excitation of the antenna is made through a coaxial line, only the TM modes (with rotational symmetry) are excited. This way, this mode is used in our analysis. Maxwell's equations, for the TM mode in the discrete form and written in the cylindrical coordinate system, are given by:

$$E_r^{n+1}(i,j)=E_r^n(i,j)-\frac{\Delta t}{\varepsilon_0\Delta z}\left[H_\phi^{n+\frac{1}{2}}(i,j)-H_\phi^{n+\frac{1}{2}}(i,j-1)\right], \quad (1)$$

$$H_\phi^{n+\frac{1}{2}}(i,j)=H_\phi^{n-\frac{1}{2}}(i,j)+\frac{\Delta t}{\mu_0\Delta r}\left[E_z^n(i,j)-E_z^n(i-1,j)\right]-\frac{\Delta t}{\mu_0\Delta z}\left[E_r^n(i,j+1)-E_r^n(i,j)\right], \quad (2)$$

$$E_z^{n+1}(i,j)=E_z^n(i,j)-\frac{\Delta t}{\varepsilon_0\Delta r}\frac{1}{r_{i+\frac{1}{2}}}\left[r_{i+1}H_\phi^{n+\frac{1}{2}}(i+1,j)-r_iH_\phi^{n+\frac{1}{2}}(i,j)\right]. \quad (3)$$

The antenna is characterized by the time $\tau_a = h/c$, that is the time needed for the light to go through the length of the antenna. In the region of analysis, one used a two-dimensional uniform mesh of 600x600, with $\Delta r = \Delta z = h/250$ and $\Delta t = h/(500.c)$.

The cylindrical monopole was excited by a Gaussian pulse of 1V. The point of excitation was the transversal section B-B' located in the line of feed (Fig.1). In order to truncate the computational domain, one used as absorbing boundary condition (ABC), Mur 1st order, which is applied over the dashed surface *S* (Fig.1).

3. PARALLEL IMPLEMENTATION OF THE FDTD CODE.

The main idea of the parallel implementation of the algorithm FDTD is based in the division of the domain of analysis in subdomains. In this technique, known as Data Decomposition or Domain Decomposition, the data of the problems are portioned among the different processors, considering that each processor executes basically the same program (source code), but on different data. This is a typical implementation of the SPMD model (*Single Program Multiple Data*) [3].

The distribution of data is manually made, i.e., it is the programmer that defines, through sending/receiving message functions, the communication among the surrounding processors in order to have a continuity in the updating of the components of field located on the interfaces of the domains. The library chosen to make the exchange of messages was the LAM-MPI, developed at the University of Ohio [4].

For the horn antenna described before and considering the *cluster* with eight machines, the domain of analysis was divided in equal subdomains along with the r-direction, resulting in matrixes of equal dimensions. Each matrix was stored and processed by only one processor, and each processor calculates the components of the electric and magnetic fields in the region of its domain. For example, for machine 1, we have (E_{r1}, E_{z1}, $H_{\phi1}$); for machine 2, we have (E_{r2}, E_{z2}, $H_{\phi2}$) and for machine 3, we have (E_{r3}, E_{z3}, $H_{\phi3}$). Fig.2 shows how the use of the components of the electric and magnetic fields are made, for the monopole antenna, on the interfaces of the domains of each machine.

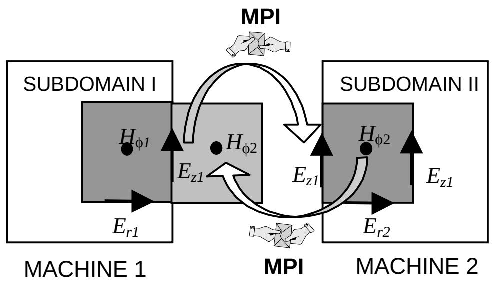

Fig.2. Updating of the components of field that are found at an interface between two regions.

Thus, different processors work simultaneously executing a copy of the program, but about several data, i.e., the processor calculates all the components of the fields of its domain passing on only those located at the interface.

4. IMPLEMENTATION AND RESULTS

The parallel FDTD program is executed on an architecture of parallel machines of *Cluster* of PCs(COPs) [5], where each machine has its own memory and local processor, what leads to the necessity of using a library that allows the exchange of messages among active processes in different machines.

4.1. Hardware and software Platform

The DEEC/UFPA Laboratory of Numerical Analysis in Electromagnetics developed one clusters named AMAZÔNIA, is constituted of eight machines, one master and seven slaves. The master has the following configuration: two Atlhon XP 1800+ processors; DDRAM memory 2 GB; two IDE ATA 133 disks of 60 GB; one RAID ATA 133 controller plate; one Gigabit NIC and one Fast Ethernet NIC. The slaves have the same configuration between them, that is: one Atlhon XP 1800+ processor; 1.5 GB of DDRAM memory, one IDE ATA 133 disks of 60 GB and one Fast Ethernet NIC, run by the operating system Linux , Red Hat 7.3 distribution.

4.2.Validation of the obtained results

To prove the gain of speed obtained with the parallelization of the FDTD code in relation to the sequential, it was made a comparison between the times of processing of the programs executed in both codes.

This result has good concordance with the result obtained by Maloney [6], with the difference that in [4] it is calculated the reflected voltage, while in Fig.3 we have the incident voltage plus the reflected voltage (total voltage). The reflected voltage can be easily obtained by subtracting the total voltage from the incident voltage.

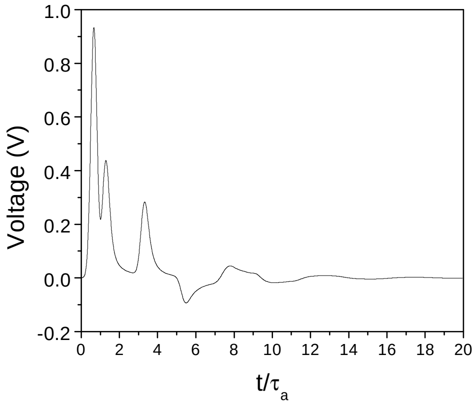

Fig.3. Voltage in the coaxial line for a cylindrical monopole antenna excited by a Gaussian pulse of 1 V: b/a=2.3, h/a=32.8, and τ_p / τ_a =1.61x10^{-1}.

Figure 4 shows the distribution of the E_z electric field component in the analysis region after 1200 iteractions in the time for the monopole antenna. In this case the AMAZÔNIA cluster was used and each square represent the results of each machine.

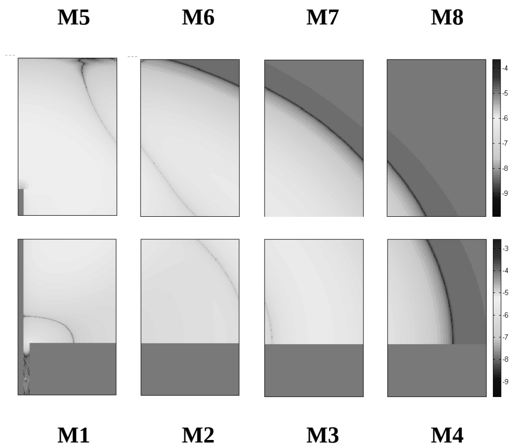

Fig. 4 Distribution of the eletric field component E_z in the analysis region after 1200 iteractions in the time.

In Fig.5, the time of execution for the monopole antenna is represented for both sequential and parallel processing. In the analysis of cylindrical monopole antenna it was used a two-dimensional mesh of 600x600 and 10000 iterations in the time.

In this work, the definition of the *speedup* is $S = T_S/T_N$, where T_S is the time for the sequential processing and T_N is the time of the processing for a cluster with N processors [7].

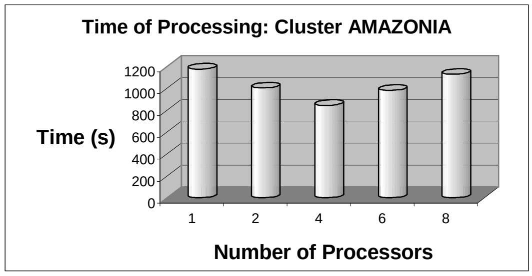

Fig.5. Time of processing for the monopole antenna

For the monopole, the results of the speedup are shown in Fig.6 and are related to both the serial execution and to the cluster, with two, four, six and eight machines.

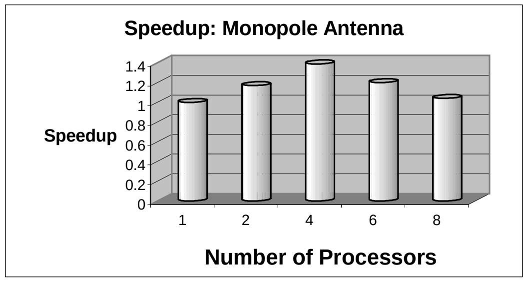

Fig. 6. Speedup versus number of processors for the monopole antenna.

5. CONCLUSIONS

The FDTD method was applied in the parallel computation of the voltage in the feed line of a monopole antenna.

The results obtained for each case analysed, both in the parallel and sequential processing, are identical and present an excellent concordance with those available in the literature.

The implementation of the Beowulf cluster (AMAZÔNIA), has shown to be a powerful computational tool that allows the use of the FDTD method in the solution of electromagnetic problems that need great amount of memory and long time of processing.

The parallel computation on an architecture of cluster kind is a strong tendency, for presenting an atractive cost/benefit relation and for the relative easiness of paralleling sequential codes, as for example the FDTD method.

The main goal of this article was to present the relation of processing time redution through the use of parallel computation in the cluster.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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