# The TLM-Equivalent FD-TD Analysis of Antenna Radiation Problems With the PML Absorbing Conditions

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***Abstract:*** This paper presents the applications of the TLM-equivalent FD-TD method to analysis of a three-dimensional antenna problems by using the modified perfectly matched layer (MPML). The calculations of a cavity-back antennas mounted on a conducting plane are performed and the radiation patterns of the antennas are obtained. The results demonstrate the effectiveness and efficiency of the MPML in the TLM based algorithm.

## I. Introduction

There has been on-going research and applications in which the FDTD method is used to model and predict the radiation patterns for the antennas, such as monopole, waveguide aperture, horn and microstrip antenna. In all these cases, the antennas are mounted on finite size ground plane or conducting box, and the antenna and its environment can be enclosed by the computation box. The Mur's second order absorbing boundary condition are used to truncate the computation domain.

This paper presents a three-dimensional TLM-equivalent FD-TD analysis of antenna radiation problems with the modified perfectly matched layer (MPML). First, the calculation of electric dipole on the ground plane is performed to validate the code. Then, the computation of an actual antenna - a cavity-backed dipole antenna mounted on a conducting plane is carried out. The radiation pattern of the antenna is obtained and the effectiveness and efficiency of the TLM-based FDTD algorithm are demonstrated for the practical design.

## II. Theory

The perfectly matched layer (PML) absorbing boundary condition has been shown to be very effective and efficient in a time-domain simulation [1][2]. Further enhancement of its performance has lead to various modified schemes [3][4] (and references therein). One of them is the modified PML. In spite of these developments, there have been no reports on the implementation of PML or MPML in the TLM-based numerical methods in three dimensions ([5] only shows a two dimensional implementation of PML in the TLM). In this paper, the MPML is extended to three dimensions and then implemented in the TLM-equivalent FD-TD scheme as proposed in [6]. The approach is, for the first time, applied to the calculations of antenna radiation problems.

The TLM-equivalent FD-TD method is first proposed in [6]. The grid arrangement is the same as the TLM symmetrical condensed node where all the six field components are defined at the center of a 3D cell and the tangential field components are defined on the boundary surfaces of the 3D cell. The field components at the center are updated through the finite-difference of Maxwell's equations while the boundary field components are updated through a special averaging process. This special averaging process is independent of medium types. Therefore, the implementation of MPML becomes straightforward: the MPML equations which contain the split field quantities are applied only at the center of a 3D cell while the averaging process remains unchanged.

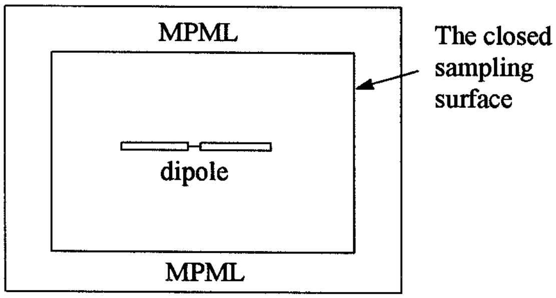


**Fig.1. MPML placement in the FDTD method**

Fig. 1 illustrates the MPML placement in the FDTD method. A closed surface on the inner surface of the MPML boundary (which encloses the antenna of interest) is selected for field sampling in space and time. Then, Maxwell's equations are solved with the TLM-based FDTD.

The procedure to obtain radiation pattern can be divided into two steps. First, in time domain, FDTD together with the MPML absorbing boundary condition is applied to simulate the electromagnetic fields. During the simulation, the time-domain field values at the sampling surface are recorded. Once the simulation is completed, the recorded field values are Fourier-transformed to get the corresponding frequency-domain field values. These frequency domain field values are then used to extract the radiation patterns by using the field equivalence principle (or more specifically, by the spatial Fourier transform).

## III. Applications

To validate our code, the TLM-equivalent FD-TD technique was first applied to a well-understood structure, a vertical infinitesimal electric dipole with different heights above an infinite electric plane conductor (or ground plane) [7] and the results were compared to the analytical solutions.

Since the FD-TD can not be performed in an infinite domain, the conducting plane needs to be removed for computation. This was achieved by using the image theory. In the image theory, the total field above the ground plane is equal to the sum of the fields originating from the actual source above the plane and the corresponding imaginary source below the plane (with the removal of the ground plane). As a result, the FD-TD computation can be performed in a finite 3D box enclosing the actual direct source and the imaginary source without the ground plane. Since the actual fields do not exist below the ground plane, the fields below the conducting plane are set to zero. Fig. 2 shows the calculated radiation patterns with different heights $h$, where $L$ means the wavelength. They are in very good agreement with the theoretical results as shown in Fig. 4.14 of [7]. This confirms the validity of the approach we used.

Once the above numerical validation was performed. A calculation of a cavity-backed dipole antenna mounted on a conducting plane as shown in Fig 3 was carried out.

In computation, the following steps were taken.

1. Select the FDTD region which encloses the whole antenna and place the PML boundaries as shown in Fig. 3.
2. Run the FDTD simulation to calculate the electromagnetic fields and record the

time-domain tangential electric field components $\boldsymbol{E_s}$ at the aperture.

3. Perform the Fourier Transform on the $\boldsymbol{E_s}$ and obtain the equivalent magnetic current density $\boldsymbol{M_s}$: $\boldsymbol{M_s} = -\boldsymbol{n} \times \boldsymbol{E_s}$
4. Take into account of the imaginary (equivalent) source, $\boldsymbol{M_s} = -2\boldsymbol{n} \times \boldsymbol{E_s}$.
5. Determine the far field radiated from $\boldsymbol{M_s}$ over the aperture by using the equivalent field principle.

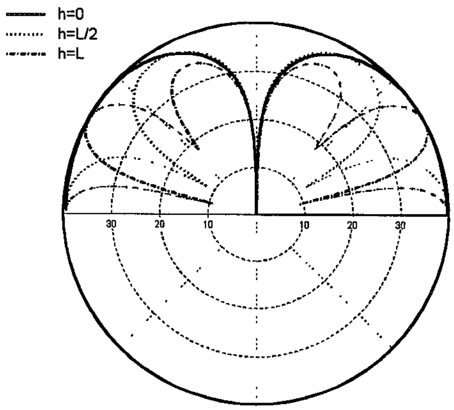


**Fig. 2. Elevation plane amplitude patterns of a vertical electric diploe above and infinite ground plane.**

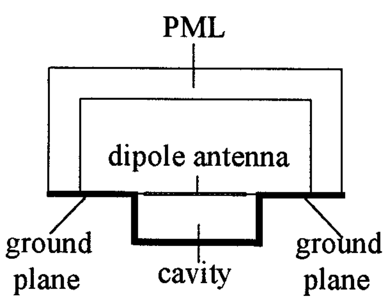


**Fig. 3. Structure of the antenna investigated**

The radiation pattern calculated in the E-plane is shown in Figure 4.

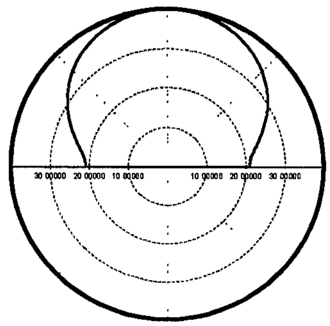

**Fig. 4. The radiation pattern obtained**

It should be noted that the actual measurement of the antenna performance is difficult to perform because of the large size of a conducting plane. The FD-TD with MPML, however, presents a solution.

## IV. Conclusions

In this paper, the MPML is implemented in the TLM-based FDTD and is used to successfully analyze and model radiation by the antenna mounted on a very large conducting plane. The effectiveness and efficiency of the MPML schemes are demonstrated for the practical antenna design using a TLM based technique.

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