HIRF Penetration and PED Coupling Analysis for Fuselage Models Using a Hybrid Subgrid FDTD(2,2)/FDTD(2,4) Method

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1 Introduction

The continuous and growing demand for new, better, and faster services, such as mobile telephony, high quality audio, high resolution video, variable rate data etc., stimulated the astonishing evolution of the communication systems, electronics and computers. With the clock speed of all electronic equipment increasing, classical engineering analysis tools have become obsolete. As the frequency of operation increases, devices become electrically large. These problems yield large computational domains and they require significant amount of computational resources, such as memory and execution time. Traditional finite methods (FDTD and FEM) are second-order accurate, thereby restricting the size of the domains that can be handled efficiently.

In this paper, some of the problems associated with perfect electric conductor (PEC) boundary conditions in the context of FDTD(2,4) are discussed. Also, a hybrid technique of FDTD(2,4) with subgrid FDTD(2,2) is formulated and applied to practical engineering problems. FDTD(2,2) is the standard second-order accurate both in time and space FDTD whereas FDTD(2,4) is the second-order accurate in time and fourth-order accurate in space FDTD.

Specifically, two very important EMI problems are examined. First, the shielding effectiveness of a simplified scaled model of a Boeing 757 aircraft is calculated. A critical EMI/EMC issue that is relevant to all aviation, and which has lately attracted a lot of attention, concerns the penetration of High Intensity Radiated Fields (HIRF) into conducting enclosures via apertures. Both the standard FDTD(2,2) and the hybrid of subgrid FDTD(2,2) and FDTD(2,4) are used for the predictions which are validated by comparison with measurements. Second, the coupling of personal electronic devices (PEDs) is examined for the scaled fuselage by modeling the coupling between a PED antenna inside the fuselage and an antenna mounted on the exterior skin of the fuselage. The EMI generated by PEDs is another very important issue for all aviation. Again both the standard FDTD(2,2) and the hybrid of subgrid FDTD(2,2)/FDTD(2,4) are applied for the predictions which are validated by comparison with measurements.

2 Hybrid of Subgrid FDTD(2,2) and FDTD(2,4)

The proposed approach in this section consists of combining a subgridding technique with a higher-order scheme. Subgridding techniques have been used in the past in the context of the standard FDTD [1], [2]. In [3], a hybrid formulation of FDTD(2,4) and subgrid

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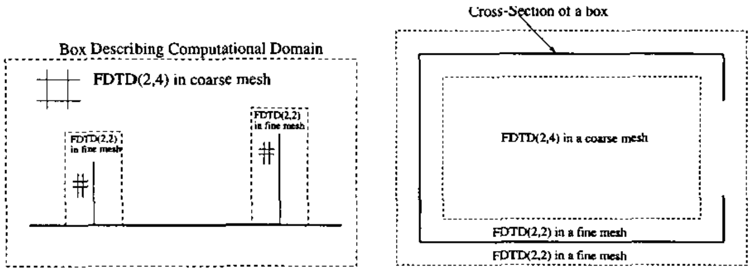
FDTD(2,2) was presented. The formulation of that hybrid method assumed that everywhere in the domain FDTD(2,4) is applied except small areas of the domain where subgrid FDTD(2,2) is used. These parts where subgrid FDTD(2,2) is used were assumed to be internal to the entire FDTD(2,4) domain. For example, see in Fig. 1(a) the domain of the two monopoles that was analyzed in [3], and notice that subgrid FDTD(2,2) was used only around the two monopoles.



(a) (b)

Figure 1: Schematic visualization of the hybrid method of FDTD(2,4) and subgrid FDTD(2,2) presented in the previous section.

However, there might exist problems where the opposite configuration of meshes (coarse and thin) occurs, i.e., the area where FDTD(2,4) is used is contained in the subgrid FDTD(2,2) domain. One example of such a case comes from shielding effectiveness analysis of electrically large rectangular enclosures. In these cases, the largest part of the computational domain is the interior of the enclosures, and the problem of boundary conditions arises near the walls of the enclosures. In such cases, it is desired to simulate the propagation inside the box using a higher-order method such as FDTD(2,4). In addition, near the walls of the boxes a subgrid FDTD(2,2) method should be used in order to represent accurately the PEC boundary conditions, and successfully simulate the penetration mechanisms. FDTD(2,2) is used near the walls instead of FDTD(2,4) since FDTD(2,4) exhibits an inherent artificial penetration through thin PEC films as shown above. Also, as discussed in [4] stable higher-order boundary conditions that would simulate correct PEC discontinuities do not exist and they are very challenging to derive. Therefore, subgrid FDTD(2,2) is hybridized with FDTD(2,4) to resolve all these issues. Following such a procedure, yields tremendous savings in memory and/or time depending on the particular problem. A schematic representation of such a problem is depicted in Fig. 1(b). In order to implement this new type of hybrid, a new formulation has to be implemented [4]. This new hybrid is named subgrid FDTD(2,2)/FDTD(2,4) which is the reverse of the name of the hybrid method in [3].

To illustrate the savings that can result in the numerical FDTD analysis of shielding effectiveness, by using this new hybrid method, some examples are presented. One of the main purposes of this paper is to be able to efficiently and accurately analyze the shielding effectiveness of a full-scale fuselage. Results for such analyses will be presented later where a simplified scaled model of a Boeing 757 aircraft is examined. This scaled model has the following dimensions: 155 cm long by 20 cm wide by 24 cm high. In order to accurately simulate this problem with the standard FDTD(2,2) up to 9 GHz, a cell size of 2.5 mm (or $\lambda/13$ at 9 GHz) has to be used. This mesh yields a very large computational domain; 620 × 80 × 96 cells. This domain requires $M_{FDTD(2,2)} = 114$ Mbytes just for the electric and magnetic field components. Therefore, simulating this problem requires a very large amount of computational resources, memory as well as time. Especially, the memory issue is more restrictive since if the required memory for a simulation is not available, then the simulation cannot be performed.

However, if the new hybrid method of subgrid FDTD(2,2)/FDTD(2,4) is applied to the same problem, significant savings in memory are achieved. The total amount of memory for the hybrid subgrid FDTD(2,2)/FDTD(2,4) method is only $M_{hybrid} = 48$ Mbytes which is 2.5 times smaller than the memory required by the standard FDTD(2,2) code (114 Mbytes).

3 HIRF Penetration Through a Scaled Fuselage

The geometry under analysis is a simplified scaled model of a Boeing 757 aircraft. Its internal dimensions are 155 cm long by 20 cm wide by 24 cm high. These dimensions are sufficient to enclose a 1:20 scale model of a Boeing 757 fuselage that is shortened by 25%. The the CAD model of the simplified fuselage is illustrated in Fig. 2.

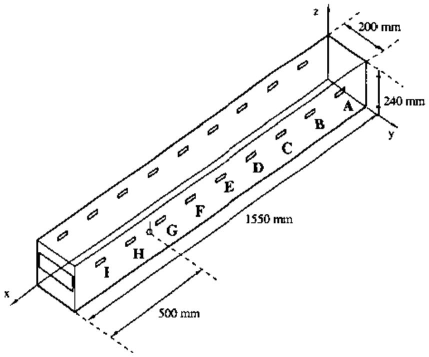
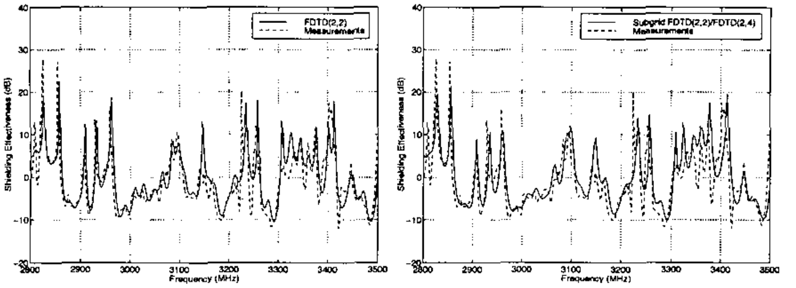


Figure 2: Simplified scaled model of a fuselage.

Here, predictions of the shielding effectiveness for the simplified fuselage are presented. First, the predictions are performed using the standard second-order accurate both in time and space FDTD(2,2) method using a cell size of 2.5 mm (or $\lambda/13$ at 9 GHz). The FDTD(2,2) computations are shown and compared to measurements in Fig. 3(a) for one of the several bands that were analyzed. Then, the hybrid method of subgrid FDTD(2,2)/FDTD(2,4), presented above is applied to compute the shielding effectiveness of the scaled fuselage. All the hybrid predictions are performed using a cell size of 2.5 mm (or $\lambda/13$ at 9 GHz) for the fine grid, and of 7.5 mm (or $\lambda/3$ at 9 GHz) for the coarse grid. The calculations of the hybrid are shown in Fig. 3(b). By comparing Fig. 3(a) with Fig. 3(b), it is observed that the hybrid method, even with coarser meshing for FDTD(2,4), gives very similar results for shielding effectiveness as the ones of the standard FDTD(2,2) alone (with a cell size of 2.5 mm). Notice that even though most of the interior of the fuselage is simulated using a quite coarse cell size of 7.5 mm, the accuracy is retained as a higher-order scheme is applied [FDTD(2,4)]. Also, the predictions of the hybrid method agree very well with the measurements. This simulation again verifies the accuracy and efficacy of the hybrid method. Concerning the PED analysis results, they will not be reported here due to lack of space, but they will be presented in the conference.



(a) (b)

Figure 3: Shielding effectiveness of the scaled fuselage for azimuthal incident angle of 0°.

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