MODIFIED EQUIVALENT BOUNDARY SURFACE PRINCIPLES USING HYBRID FEM-FDTD ELECTROMAGNETIC MODELS

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***Abstract* - A modified boundary surface between the two domains in the hybrid FEM-FDTD technique is presented. This permits a heterogeneous surface to be imposed, allowing selected parts to be represented as being conducting or non-conducting. This enables a reduced surface size to be used in cases where an antenna is above a conducting plane, as well as facilitating a range of other practical scenarios. Examples presented show stable results and good agreement with published data.**

Keywords - Hybrid methods, Finite Element Method (FEM), Finite Difference Time Domain (FDTD).

I. INTRODUCTION

The finite element method (FEM) is widely used in computation of unbounded static and quasi-static electric and magnetic fields at DC and low frequencies, and for enclosed systems (cavities etc) at high frequencies. However, there have been problems in applying the method to high-frequency open-field (radiation and scattering) problems due to the relatively large size of the computational tasks that result. The finite-difference time-domain (FDTD) scheme is very popular for electromagnetic modeling because of its simplicity and efficiency. One drawback of FDTD is the staircase approximation of oblique boundaries, which often gives poor accuracy. The finite-element method (FEM) allows good approximations of complex boundaries and with edge elements it performs well for Maxwell's equations [1]. An obvious compromise is a hybrid that applies FDTD in large volumes, combined with FEM around regions with complex structure: the FEM may be applied in frequency domain to achieve very efficient solutions. Previously attempted hybrids of this type have only used time-domain FEM [2] and some have shown late-time instabilities [3,4].

II. METHOD

The coupling between the hybridised methods is computed by using the equivalence-principle (EP) theorem. The objects in the different domains are not physically connected but need only be separated by a small distance, sufficient to permit the surface on which the equivalence principle is enforced to be located between them.

In this paper, a modified EP surface in which one or more faces are replaced by a conducting surface was investigated (see Fig. 1). In this modification, the conducting surface can be extended beyond the size of the EP surface, for example a handset box for a mobile phone, where only the antenna part is within the EP surface. The Inverted F-Antenna (IFA) was chosen for evaluation purposes since it is a common mobile phone design. The antenna, including a finite ground plane, was modelled by using a standard FEM software package [5]. In the first test, the EP surface boundary was chosen to reach to the edges of the finite ground plane representing the adjacent surface of the phone body (see Fig. 1a) and then the size of the EP surface was reduced and the antenna performance was again predicted, with and without the presence of an arbitrary conducting-sheet scatterer (see Fig. 1b), inserted below the 'ground plane'. Outside the FEM domain, the rest of the problem space was inserted in an FDTD region.

The procedure can be extended to two or more conducting surfaces partially coinciding with the EP surface. Due to the differing structures of FEM (normally non-uniform tetrahedral meshing) and FDTD (normally uniform rectangular cell distributions), a support program was written to link the field points that exist on either side of the EP surface.

III. SIMULATION AND RESULTS

A program was written to simulate the details presented in the previous section. The operating frequency was chosen as 1800 MHz and the handset dimensions (finite ground) were 5cm x 8cm. The antenna was designed with minimum return loss of 10dB and 9% relative bandwidth at 1800MHz. The complete FEM problem space for the examples presented stretched well beyond the EP surfaces and was of size 12cm x 9cm x 4cm, with its lower surface coincident with the finite ground plane. Outside the metallic plane, the lower surface of the FEM model used the low reflecting boundary formulation [5]. The antenna was excited by a magnetic frill through a coaxial cable of radius 2.5-mm. The FDTD cell size and the time step were 2.5mm and 3.375ps respectively. The number of the FDTD PML (perfectly matched layer) cells was 6.

Example 1: The total field (for 1 watt input power) as seen 1cm underneath the centre of the ground plane, on a line parallel to the x-axis, was examined; the scatterer plate was absent. The EP surfaces were considered at the edges of the handset (Fig. 1a) and closer to the antenna (Fig. 1b). A comparison between the two geometries, and with the pure MoM [6] is shown in Fig. 2. The FDTD problem space dimension was 54 x 54 x 38 cells. The EP surface sizes for Figs 1a and 1b were 5cm x 8cm x 3cm (equivalent to 32 x 20 x 12 cells inside the FDTD method) and 3cm x 4cm x 3cm (equivalent to 12 x 16 x 12 cells inside FDTD) respectively. The results show good agreement for all proposed equivalent surfaces. The results also show that the difference between the total field and the scattered fields in the case of the FEM/FDTD hybrid method was 25 to 30 dB: this is in accord with expectations. However, the computer memory needed for the field points on the surface boundary with the modified equivalent surface (Fig. 1b) was reduced by 70% compared to the one in Fig. 1a and this directly contributed to reduce the execution time in updating the boundary difference equation inside the FDTD method.

Example 2: In this example, a scatterer was considered underneath the handset as shown in Fig. 1b. The scatterer was a conducting surface of size 5cm x 6cm which is equivalent to 20 x 24 cells inside the FDTD method. The variations of the input impedance for different distances between the handset and the scatterer were computed and are shown in Fig. 3. The computed results were in acceptable agreement with those calculated from pure MoM [6].

IV. CONCLUSIONS

A hybridisation technique between the FEM and FDTD has been presented. An equivalence-principle surface, including a partial conducting surface, was successfully implemented through the boundary that coupled the two methods. A reduced-size EP surface has been presented and was found sufficient to predict the antenna performance with and without the presence of a nearby scatterer. This saved approximately 70% of the required memory locations of the field points between the two domains and also accelerated the updating boundary equations inside the FDTD method. The results are stable and show good agreement between the different techniques.

V. REFERENCES

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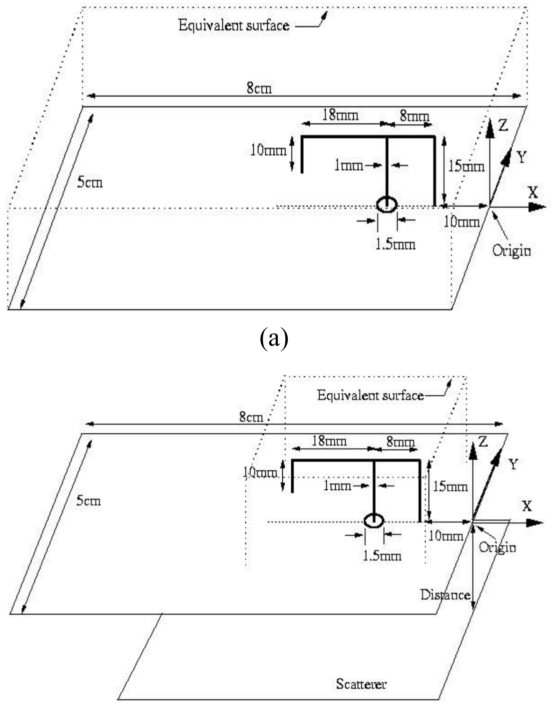
Figures captions:

Fig. 1 Antenna structure with EP surfaces, either reaching to the edges of the ground plane (a), or enclosing a reduced small volume (b). The lower scatterer plate was introduced in later tests (Fig. 3).



(a)

(b)

Figure 1

Fig. 2 The total field 1cm underneath the longitudinal centre line of the ground plane (no scatterer present).

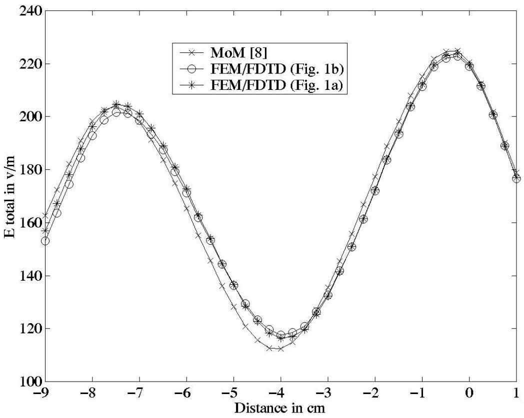


Figure 2

Fig. 3 The variations of the input impedance versus distance between the ground plane and the scatterer.

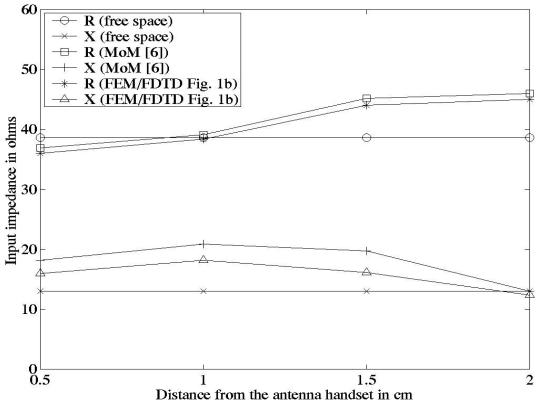

R (free space)
X (free space)
R (MoM [6])
X (MoM [6])
R (FEM/FDTD Fig. 1b)
X (FEM/FDTD Fig. 1b)
Input impedance in ohms
60
50
40
30
20
10
0
0.5
1
1.5
2
Distance from the antenna handset in cm

Figure 3