Simulation of Radiation Performance for Mobile Antennas using a Hybrid FEM-FDTD Computational Technique

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Abstract

The objective of this paper is to study the radiation performance of mobile handsets antenna by using the hybrid method between the Finite-Element Method (FEM) and the Finite Difference Time Domain (FDTD), as applied to computational electromagnetic studies, e.g. antenna scattering modelling problems. An application of modified equivalent surface boundary using the hybrid FEM-FDTD technique [1] is presented and discussed in terms of the memory locations and processing time required for updating the equivalent surface currents from FEM to FDTD methods. A reduced equivalent surface size that encloses the radiating part of the antenna is studied and the results are compared with different sizes of the equivalent surface configurations. Several examples are presented and the results were stable and quite reasonable with published data.

1. Introduction

The FEM is already widely and successfully used in computation of static and quasi-static electric and magnetic fields at DC and low (<1 kHz) frequencies, and for enclosed systems (waveguides, cavities etc) at high frequencies [2]. However, there have been problems in applying the method to high-frequency open-field (radiation and scattering) problems for reasons that are in need of investigation. The finite-difference time-domain (FDTD) scheme [3] is very popular for electromagnetics modeling because of its simplicity and efficiency. One drawback of the 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 [4]. However, FEM requires more memory and has a higher operation count than the FDTD. An obvious remedy is a hybrid that applies FDTD in large volumes, combined with FEM near complex boundaries. Previously attempted hybrids of this type [5,6] suffer from instabilities known as late time growth.

The modified equivalent surface with one or more faces was replaced by a conducting surface was investigated (see Fig. 1). In this modification, the conducting surface can be extended beyond the size of the equivalent surface such as the handset box excluding the antenna part of the mobile phone. Normally, the frequency domain FEM was used to analyse a structure up to a few wavelengths in size and it is particularly appropriate for simulation of 1-D, 2-D and 3-D structures. However, it faces some difficulties to manage substantial volume of dielectric since the size of the interaction matrix become larger when the number of quantisation elements exceeds a few thousands. By the way, FDTD can handle substantial penetrable dielectric and partially-conducting structures such as human head since each quantisation element interacts only with its nearest neighbours and not with the entire set of elements [7].

The basic idea of the FEM-FDTD hybridisation technique has been realised in the recent past and it has been extensively studied and tested in different application [8,9]. The coupling between these methods is compute by using the equivalent principle theorem. The objects are not connected in physical manner but only separated by a small distance, sufficiently to permit the equivalent principle surface to place in isolation between them.

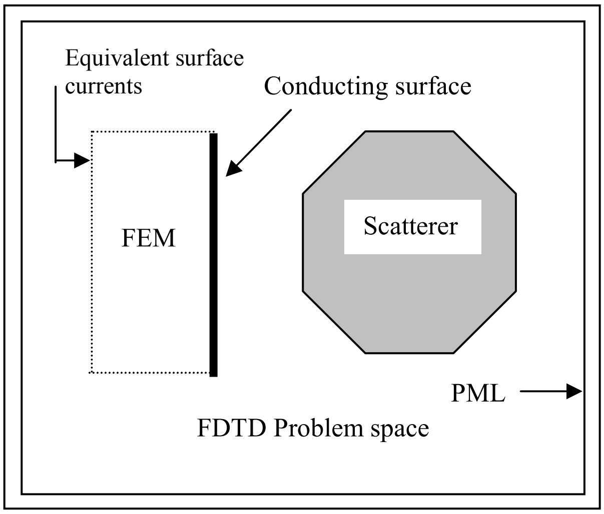


Figure 1. Basic geometry of the modified hybrid method.

In this paper, Inverted F-Antenna (IFA) has been chosen for evaluation purposes since IFA is the most familiar antenna used in mobile handset now days. The antenna is small, compact and can be mounted on one side of the Mobile handset and easily altered depends on the manufacturer needs. The antenna including the finite ground plane has been modelled by using the FEMLAB software that uses FEM principles.

Figure 2 shows the geometry and dimensions of the balanced antenna for a mobile phone. The antenna was designed first and then was mounted on top of a finite ground plane with dimension of 8 x 5 cm^2. The radiating patch consists of single patch. A 50-Ω SMA probe connector with radius 0.5 mm placed perpendicular to the ground plane, through which a coax is used H field excitation. The antenna is supported by two different sizes of shorted pins of height of 11 mm from the ground plane with the radius 0.5 mm and 2 mm, respectively. By introducing a long slit in the middle of the patch, the lower resonant frequency can be easily controlled. It should be noted that feeding strip line arranged at one side of the patch can generate combined dual-resonance naturally, whose operating frequencies can be shifted by changing the length and width of the patch. In addition, a probe feed, at the bottom edge of the strip line, can be located for good excitation of the antenna over resonant frequency bandwidths.

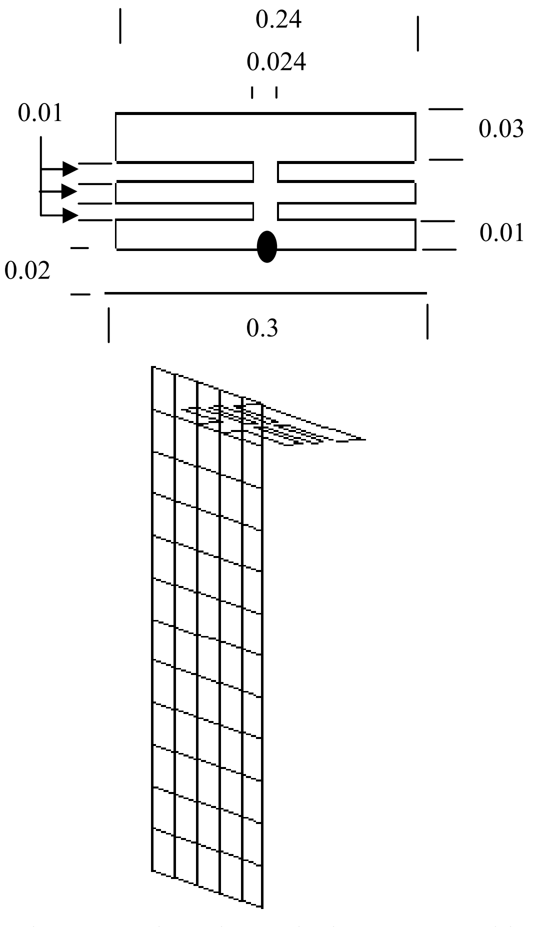


Figure 2. Balanced meander loop antenna with conducting plate (All dimensions in λ)

2. Summary of the Method

Using the surface equivalent theorem, the near-to-near and near-to-far field transformation can be extended through using FEM to FDTD modelling of 3-D scatterers and antennas. Consider Fig. 1, the fields outsides of the equivalent closed surface are obtained by placing suitable electric and magnetic current densities that satisfy the boundary conditions. The current densities are selected so that the fields inside the closed surface are zero and outside are equal to the radiation produced by the actual sources. The degree of accuracy depends on the knowledge of the tangential components of the fields over the closed surface.

Figure 1 represents schematically the most general case dealing with electromagnetic wave interactions with an arbitrary 3-D structure. It is assumed that a field (E_1, H_1) filling all of space is generated by the action of physical electric and magnetic current sources J_1 and M_1 flowing on the surface structure of interest. There are now exists a new field (E, H) inside an arbitrary closed observation surface S that completely encloses the structure. The original (E_1, H_1) will be observed outside S. The following non-physical electric and magnetic currents flowing tangentially along S must be exists to satisfy the desired situation of the field boundary conditions. Thus:

$$J_S = n \times (H_1 - H) \qquad (1)$$

$$M_S = -n \times (E_1 - E) \qquad (2)$$

Where n is the unit outward normal vector to S. J_s and M_s are the surface electric and magnetic currents. Now, the current densities can be simplified as in following:

$$J_S = n \times (H_1 - H|_{H=0}) = n \times H_1 \qquad (3)$$

$$M_S = -n \times (E_1 - E|_{E=0}) = -n \times E_1 \qquad (4)$$

The currents on surface boundary (that exclude the conducting surface currents on the handset) can be transferred to FDTD method by treating them as impressed currents. These impressed sources can be represented through the FDTD difference equations as follows:

$$E = E_{FDTD} + \frac{J_{s|S}}{\left(\frac{\varepsilon}{\Delta t} + \frac{\sigma}{2}\right)} \qquad (5)$$

$$H = H_{FDTD} + M_{s|S}\frac{\Delta t}{\mu} \qquad (6)$$

The conducting surface (finite ground or handset) will be directly modelled through the FDTD method. However, the procedure can be extended on two or more conducting surface enclosed within the equivalent surface. In general, due to the structure of non-uniform meshing (normally tetrahedral cells) used in FEM and uniform cells distribution (ex. rectangular cells) of FDTD, a support program was written to link these field points that exist on the equivalent surface.

3. Simulation and Results

The body of the handset was represented as a rectangular conducting plate with dimensions 50 mm x 120 mm (i.e. 0.3λ x 0.72λ at f = 1800MHz). The antennas were placed at a distance of 0.027λ to 0.03λ from the top surface of the handset. The total area occupied by each antenna was 0.27λ by 0.034λ, in a plane normal to the handset. Several attempts were made to achieve the best matching characteristics by varying the lengths of the meander-line arms inside the area size stated above. However, the total length of the meander was always kept between 0.5λ and λ (free-space wavelength).

The constraints on the antenna designs were, firstly, the free space resonance length required at the operating frequency and, secondly, the total area required to accommodates the antenna inside a typical phone. Subject to these considerations, the design was optimised using trial and error procedures since the degrees of freedom were already tightly constrained. The model has been shown in Figure 2.

Following establishment of the antenna design in the FEM region, each FEM antenna model was placed inside the FDTD domain using an equivalent Huygens surface at the boundary, as shown in Figure 1. The details of the method, and specific explanations of the tangential fields (E_b and H_b: the back scattered fields) and surface currents (J and M: the excitation currents) shown in Figure 1 are given fully in refs. [10,11].

The cell size used in the FDTD portion was 2.5 mm (cubes) and the size of the problem space was 127 × 90 × 127 cells. Within this, the Huygens surface size was 36 × 36 × 74 cells. The head model was a realistic head image, taken from an MRI scan of a real human head, and segmented into 13 different tissue types [12]. The exterior of the FDTD region was terminated with a perfectly matched layer 6 cells deep, with a geometric grading factor of 5.34. The computed results with and without the human head are summarised as follows:

The input impedance versus the frequency, without the human head, for meander-loop balanced antenna is presented in Figure 3 and the return loss (S_{11}) for meander-loop balanced and unbalance antennas in Figure 4. The bandwidth for the unbalanced antenna is much better than the bandwidth for the balanced antenna. The modified equivalent surface was placed near to the handset, with size 1cm x 4.5cm x 3cm (4 x 18 x 12 cells). The FDTD problem space dimension was 48 x 36 x 36 cells. The near field contours for the two antenna types, without an adjacent scatterer, for three different cuts inside the FDTD problem space are shown in Figure 5. As shown, the difference between the total field and the scattered fields was 25 to 30 dB which is quite reasonable. The radiation patterns for the respective cuts are shown in Figure 6 which are also in line with physical expectations.

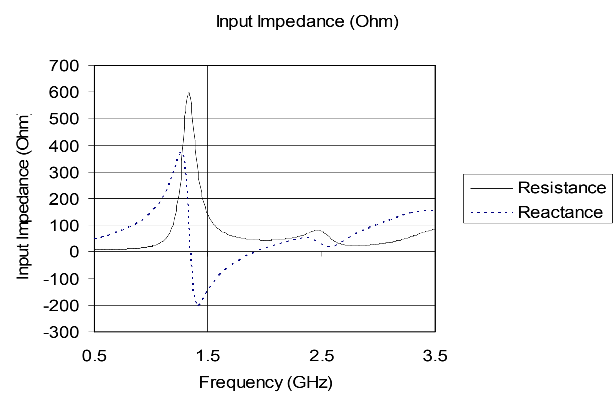


Figure 3. Input Impedance

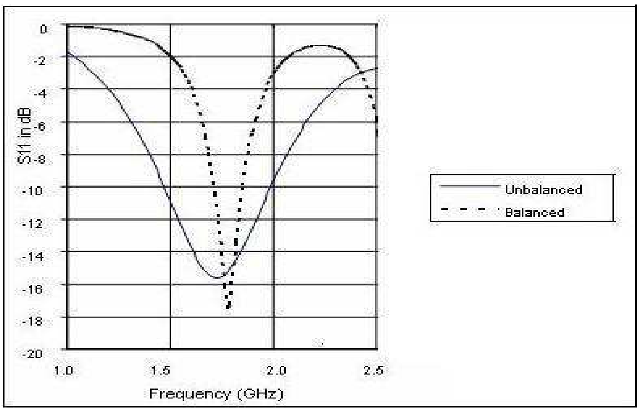
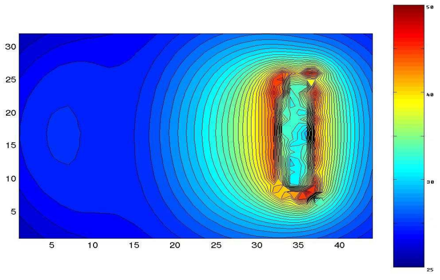
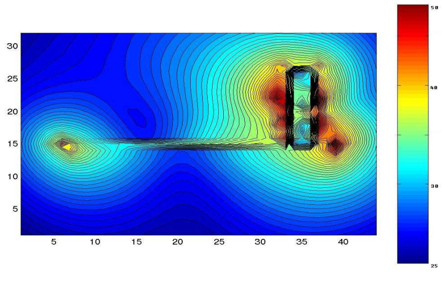


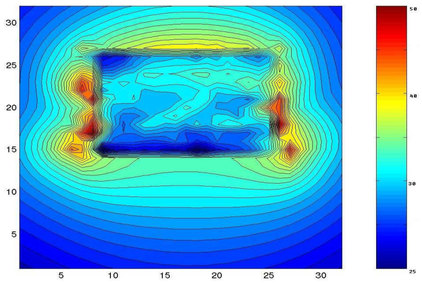
Figure 4. Return Loss



(a) x-y plane

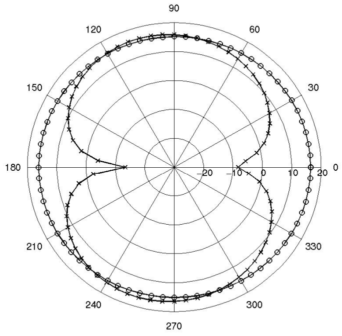


(b) x-z plane

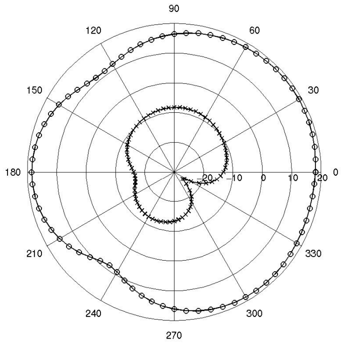


(c) y-z plane

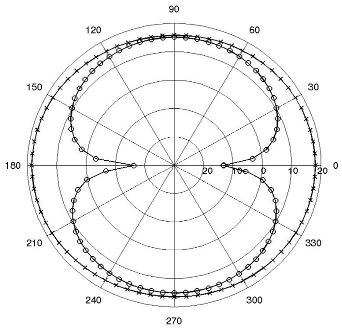
Figure 5. Near field contours in dBs on the principal median planes: (a) x-y plane (b) x-z plane and (c) y-z plane for the balanced antenna.



(a) x-y plane

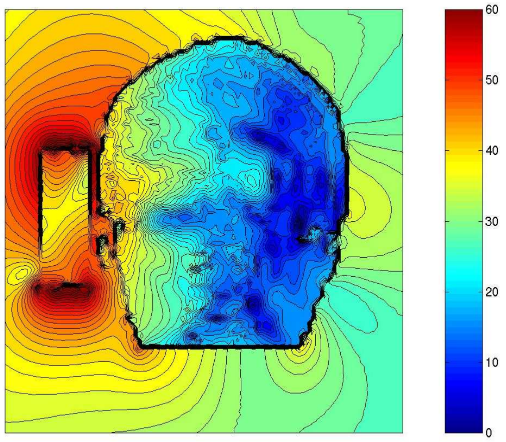


(b) x-z plane

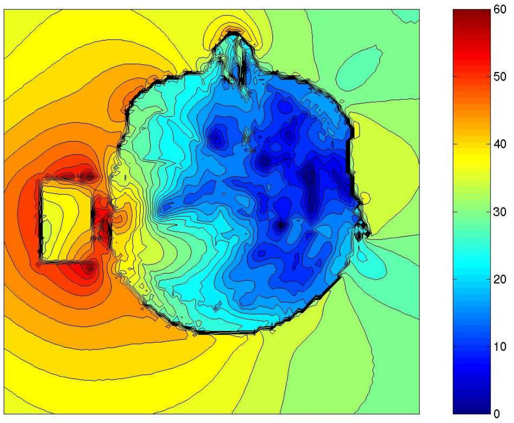


(c) y-z plane

Figure 6 Example 5 near field contours in dBs on the principal planes:(a) x-y plane (b) x-z plane and (c) y-z plane for the balanced antenna: (E_θ - ooo, E_ϕ - xxx).



(a)



(b)

Figure 7 SAR distribution in dBs normalised to 1 watt input power at: (a) x-z plane, (b) y-z plane for balanced antenna.

4. Conclusions

Hybridisation technique between the FEM and FDTD has been presented. Equivalent surface including a conducting surface was successfully implemented through the boundary that coupled the two methods. A reduced equivalent surface was presented and was found sufficient to predict the antenna performance. This save 70% of the required memory locations of the field points between the two domains and also speed up the updating boundary equations inside the FDTD method. The results are stable and show a good agreement with different technique.

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