Fast and Efficient FDTD Simulations of Personal Wireless Devices for SAR Compliance Testing and Antenna Design

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Introduction

We have used an efficient implementation of the PML boundary according to the formulation proposed by Sullivan to truncate the human head model for cellular telephone simulations. Different from the truncation method previously presented by the authors, the new method does not require any symmetry considerations.

Because of the basic observation that a large percentage of the power absorbed in the human head model is concentrated in the proximal ear and a limited volume of the head behind it, it was possible to gradually truncate the head model in the ear-to-ear (x) direction, back-to-front (y) direction, and bottom-to-top (z) directions.

It was found that it is possible to retain just 4% of the original volume of the head model to obtain 1- and 10-g SARs within 1% accuracy at the frequency of 1900 MHz. At the frequency of 835 MHz, since the actual shape of the head in proximity of the ear region affects the radiation from the cellular telephone and its radiated power, it was necessary to retain approximately 15% of the head model to achieve 1% accuracy for the 1- and 10-g SARs.

The method allowed us to complete cellular telephone simulations in less than 5 minutes at the frequency of 1900 MHz using a commonly available PC. The method can be efficiently used for SAR compliance testing of wireless devices and may also be used as an efficient tool for the design of handset antennas.

FDTD Modeling

The FDTD method is the preferred technique for the analysis of coupling between wireless devices and the human head, both from the safety certification point of view [1] and design of antennas that operate in the presence of the head model. A Finite-Difference Time-Domain code [2] with PML boundary conditions [3] implemented according to the formulation proposed by Sullivan [4] has been developed. This particular formulation allows one to terminate any given material directly in the PML layers, without virtually any reflection between the region of interest and the PML absorbing boundaries. The formulation uses the

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electric displacement field **D**, electric field **E**, and magnetic field **H** rather than only the electric and magnetic fields as in the usual implementation. This formulation has the advantage of making the PML properties completely independent of the background medium. This characteristic makes possible to practically immerse in the PML layers the regions of the head model of little or no interest for SAR certification and antenna design. In this way, we were able to minimize the FDTD volume to be considered, leaving thereby just a small percentage of the volume of the original head model for simulation. No reflections were observed at the interfaces between the PML layers and the head model.

The head model has been derived from MRI scans, and 31 tissue types have been identified. The original model of resolution 2 x 2 x 3 mm has been first subdivided into 1 mm cube cells, and then resampled to obtain a model with a cubical resolution of 3 x 3 x 3 mm. The resulting head model is composed of 69x76x85 cells in the x, y, and z direction, respectively. The 1-g and 10-g average SARs have been calculated by means of a post-processing routine. Each cube of tissue in the head model weighing between 1 and 1.2 g have been considered for the 1 g average SAR, while cubes weighing 10 to 11 g have been retained for the 10 g average SAR computations.

In this paper, the telephone has been modeled by means of a 2.4 x 5.4 x 15 cm plastic covered metal box, equipped with a $\lambda/4$ monopole antenna mounted on the front-left corner of the handset. No hand has been considered in the simulations. The radiated power is 600 mW at the frequency of 835 MHz, and 125 mW at 1900 MHz.

The FDTD space has been progressively reduced in the ear-to-ear (x) direction first, by gradually immersing vertical cross-section of the head model in the right PML absorbing layers. A similar procedure has been used for the remaining two directions. In this way, we have progressively reduced the FDTD space from 69 to 13 cells in the x direction, from 76 to 18 cells in the y direction, and from 85 to 70 cells in the z direction when possible.

Therefore, the original model, composed of a total of 445,740 cubical cells, has been progressively reduced in all the directions down to 16,380 total cells, which correspond to a memory saving on the order of 96 %.

Results

Table 1 shows the 1g average SARs obtained at the two considered frequencies of 1900 MHz and 835 MHz for the full models. In the same table, we also give the percentage truncations for both x and y directions necessary to obtain results within 1% and 5%,respectively. Furthermore we also give the memory requirements for the considered truncations. We have found that, at the higher frequency of 1900 MHz, truncation in both x and y directions resulted in extremely accurate results (less than 1 % error). In fact, at this frequency the absorbed power is highly concentrated in the ear region and a very small volume behind it. In this case, truncations up to 81 % in the x direction and up to 76 % in the y direction did not materially affect the accuracy of the results. We can also notice that the truncated model requires only 13 Mb, which is approximately 6 times less than the memory requirement for the full model.

At the lower frequency of 835 MHz, we have found that to obtain results within 1% accuracy, only truncations in the ear-to-ear directions were allowed. In this case the memory savings are on the order of 55 %. Results within 5% were obtained if truncations in the y direction were limited to 30%, with achieved memory savings on the order of 65 %.

Figure 1 shows a x-y cross section (for a layer that is 6 mm below the antenna feed-point) of the SAR distribution in the human head model for the full model (a) and a truncated model (b) (with 81 % truncation in the x direction and 61 % truncation in the y direction,respectively). Results are shown in logarithmic scale. The agreement of the SAR distributions for the truncated model and the full model is excellent. It is possible to observe that virtually no reflections arise from either truncation, in the x or y directions.

Lastly, figure 2 shows a comparison of the radiation patterns obtained at the frequency of 1900 MHz for the full model and the half truncated model. The two patterns compare very well. We have found that to obtain an accurate radiation pattern less than half a head model should not be used. This method could be used therefore also for the design of antennas for personal wireless devices.

References

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Table 1: 1g av SARs for the full models and maximum truncations allowed to obtain 1 % and 5 % of accuracy. Memory requirements are also given.

Frequency (MHz)	1 g av. SAR (W/kg) Full Model	% of Truncation (1 % accuracy)	% of Truncation (5 % accuracy)
1900 MHz	1.11 (65 Mb)	81 % x - 61 % y 96 % volume (13 Mb)	81 % x - 61 % y 96 % volume (13 Mb)
835 MHz	2.49	81 % x – 0 % y 81 % volume	81 % x – 30 % y 87 % volume

	(65 Mb)	(26 Mb)	(21 Mb)

(a)

(b)

Figure 1. x-y cross section of the SAR distribution (for a layer that is 6 mm below the antenna feed-point) in the human head model for the full model (a) and a truncated model (b) (81 % truncation in the x direction and 61 % truncation in the y direction, truncation volume 96 %). Frequency=1900 MHz.

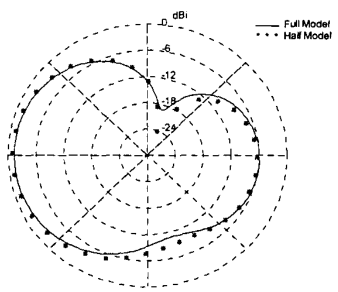

Figure 2. Radiation patterns for the full model and the half truncated model. Frequency=1900 MHz.