New Techniques for FDTD calculation of the SAR induced in the human head by wireless communication devices

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***Abstract* —This paper focuses on new techniques for FDTD (Finite Difference Time Domain) calculation of the SAR (Specific Absorption Rate) induced by wireless communication devices in the user's head. The implementation of the assessment- and averaging procedure proposed by recent standards into the EMPIRE^{TM} FDTD field solver [1] is presented. This procedure is applied to a benchmark example of a standard mobile phone model attached to different phantoms of the human head. One is the homogeneous SAM (Specific Anthropomorphic Mannequin), the other is a detailed inhomogeneous head model based on anatomical data from the *Visible Human Project* [2].**

I. INTRODUCTION

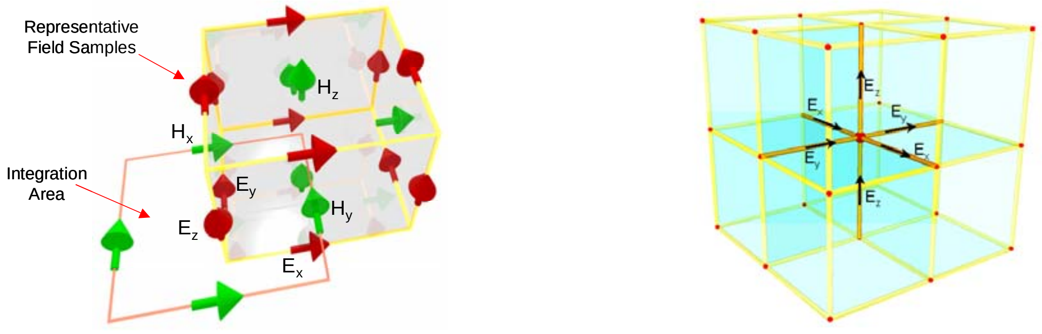
The absorption of electromagnetic energy in the human tissue (*SAR* – Specific Absorption Rate) generated by mobile phones is a point of critical public discussions because of possible health risks. To release a new mobile on the US market the mobile manufacturer has to show compliance to several FCC (Federal Communications Commission) regulations including the restrictions to ensure human safety in electromagnetic fields according to IEEE Std C95.1-1999 [3]. In late 2000, manufacturers within the MMF (Mobile Manufacturers Forum) decided to begin the reporting of SAR values on a global basis consistent with their commitment to consumers to provide all relevant and useful information on their phones. Meanwhile, there are standards about how to evaluate the SAR induced by mobile phones in the head of the user. EN 50361 [5] is such a standard which requires measurements using sophisticated measurement equipment like the DASY (Dosimetric Assessment System) by *Schmid & Partner Engineering*. For compliance testing it is required to perform measurements on the final mobile, - it is not sufficient to carry out numerical simulations. Nevertheless numerical simulations can be a useful assistance in the design phase of a new mobile or, for scientific reason, to learn more about the general interaction between mobile and user. Numerical dosimetry is a difficult task and until now the results from different researchers vary in a large amount according to their choice of the phantom, the numerical modeling and the averaging procedures they use. At the moment working group 2 within the IEEE SCC-34 subcommittee 2 under the coordination of the FDA (Food and Drug Administration) focuses on setting up a new standard (IEEE P1529) as a recommended practice for numerical investigation of the SAR induced by mobile phones in the human head [6]. This standard aims to define the way of modeling the problem and procedures for the SAR assessment and averaging using FDTD simulation.

II. CALCULATION METHOD

A. Field Interpolation and material parameter averaging

In this paper the electromagnetic field simulator EMPIRE™ [1] from IMST is used. EMPIRE™ applies the finite-difference time-domain (FDTD) method in order to solve Maxwell's equation for a given initial boundary problem. Fig. 1a shows the arrangement of the field components in the so called Yee-cell.

The field components are not defined at a common point in the centre of the cell, but arranged in a way that enables an easy calculation of the curls in Faradays and Amperes law. For the later calculation of the SAR in a certain cube it is necessary to average the de-located field components and find the averaged material parameters which are associated with this cube (voxel). As shown in Fig. 1b so called 6-component method to define the equivalent electric field on the corner of the cube is applied. It is also possible to define the equivalent electric field in the centre of the cube by a so called 12-component approach. The conductivity for this cube can be either averaged from the eight surround cubes or the maximum conductivity can be chosen. For this investigation the algorithm which uses maximum conductivity is chosen to get a worst case estimation of the maximum SAR value.



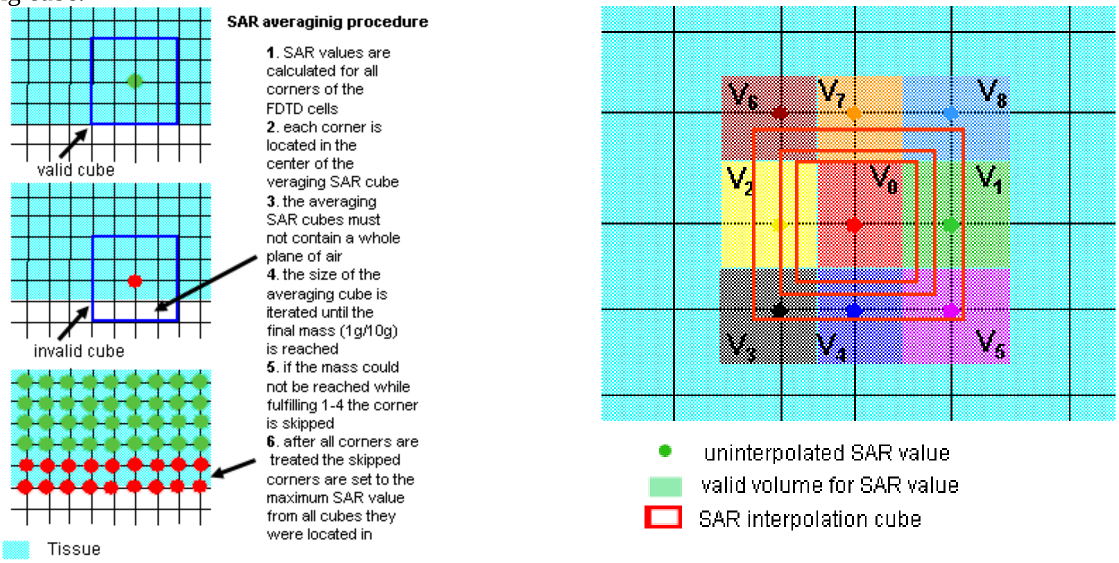
a) Definition of the electric- and magnetic-field components in a Yee cell.

b) Field- and material parameter averaging.

Fig. 1: Field components location and averaging for SAR calculation

B. SAR Averaging

SAR averaging over a certain mass of tissue is always needed to discuss SAR values with respect to different standards. For mobile phones the spatial distribution of the SAR in the human head is typically averaged over cubes of 1 g or 10 g, depending on the standard considered. For numerical determination of the SAR it is even more important to apply a certain averaging to the SAR distribution rather than to look at not averaged peak values. The segmentation of the curved shape of a body by a rectangular mesh leads to *staircasing* which causes local over- or underestimation of the field values in these voxels. Assuming that we use (for simplicity) a homogeneous mesh of 1 mm, a cube of 1 g will contain 1000 voxels, and thus the error will be statistically diminished due to over- and underestimation in specific voxels at the border of the material distribution. However, it is clear that the absolute value calculated still depends on the specific algorithm used for the averaging as it has to follow certain rules at rounded surfaces or to consider a graded mesh. The draft version of IEEE P1529 [6] refers to averaging techniques set in the standard IEEE Std C95.3-2002 [7] for measurement techniques as well as computational techniques. The recommended procedures are divided into several steps. The calculation procedure for a FDTD grid with a homogeneous mesh is described in Fig. 2a. In order to find the absolute maximum of the averaged SAR in the head, the procedure is applied to the whole tissue volume. One after the other, each voxel is set to be a centre of an averaging cube.



SAR averaginig procedure

1. SAR values are calculated for all corners of the FDTD cells
2. each corner is located in the center of the veraging SAR cube
3. the averaging SAR cubes must not contain a whole plane of air
4. the size of the averaging cube is iterated until the final mass (1g/10g) is reached
5. if the mass could not be reached while fulfilling 1-4 the corner is skipped
6. after all corners are treated the skipped corners are set to the maximum SAR value from all cubes they were located in

a) SAR averaging procedure over certain cubes of mass (1g, 10g) in accordance with IEEE Std C95.3-2002.

b) Iterative procedure to generate an averaged SAR distribution for the whole tissue volume.

Fig. 2: SAR averaging procedure

To reach the required mass as accurate as possible and to allow the appliance of the interpolation algorithm also for a FDTD code with a graded mesh, a special mass averaging is used in addition (see Fig. 2b).

The uninterpolated SAR values are in the first step calculated at the corners of all cubes. They are assigned to a volume which extends half a cell to all directions from the corner. In the next step a SAR interpolation cube with the corner as center is created. This cube size is increased iteratively until the final mass size (e.g. 1 g) is reached. Partly covered cells are considered respectively their volume part.Using this algorithm enables the determination of the absolute maximum of the averaged SAR in the whole tissue on the one hand. Moreover it is possible to generate a distribution plot of the averaged SAR over the whole tissue distribution, which does also not suffer from staircasing.

III. SAR INDUCED IN THE HUMAN HEAD BY MOBILE PHONES

As an example the SAR induced by a standard mobile phone in two different phantoms of the human head is investigated. The presented example belongs to a benchmark study performed in the evaluation of the new standard IEEE P1529 [6] using different FDTD field solvers. The intercomparison of the results from all participants will be published by the committee.

The first investigated phantom, the SAM phantom (Fig. 3a), is a standardized homogeneous phantom also used in SAR compliance testing according to different standards. The phantom consists of a 2mm thick plastic shell (ε_r=5, σ=0.0016 S/m) which is filled with a tissue simulating liquid. The parameters of the liquid are chosen to fit to the brain tissue parameters for the investigated frequency (835 MHz: ε_r=41.5, σ=0.9 and 1900 MHz: ε_r=40, σ=1.4).

a) Standard phone model attached to the SAM phantom in "cheek-position".

b) Standard phone model attached to the inhomogeneous head model in "cheek-position" (voxel size: 1mm).

Fig. 3: Simulation model of the mobile phone attached to the SAM phantom / inhomogeneous human head

Within EMPIRE™'s graphical user interface GANYMEDE™ a 3d object of the SAM can directly be imported from an STL file and can be rotated/moved as any other object.

The inhomogeneous head model (Fig. 3b) is based on data from the *Visible Human Project* [1]. The model is segmented into 1 mm voxels with more than 40 different tissue parameters. The dielectric parameters of the different tissues are automatically calculated for the selected frequency.

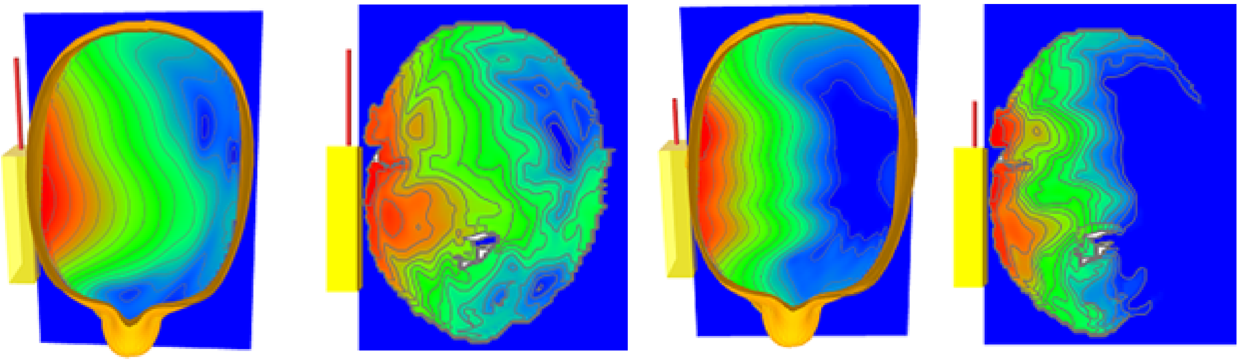
A voxel editor, available with EMPIRE™ allows to apply modification (rotations, change of material parameters or any voxel manipulation) to the model which is needed to adjust the orientation of the head with respect to the mobile in order to reach the so called *cheek position.*

The *cheek position* is coarsely spoken a position where the mobile phone is aligned parallel to a virtual line which connects the mouth and the pinna while it touches the pinna and the cheek [5].

The generic phone is composed of a solid plastic body (gray) 102 mm high, 42 mm wide, and 21 mm thick. An XZ-plane, 1 mm thick, of perfect electrical conductor (PEC) material (blue) is used as ground plane. An antenna (length 71 mm for 835 MHz and 36 mm for 1900 MHz) is excited with a lumped source against the ground plane.

The SAR calculation is performed for two frequencies (835 MHz and 1900 MHz) for both phantoms. Note: All calculated SAR values are normalized to 1W net input power. Fig. 4 shows the resulting SAR values in a color coded plot. The SAR values are scaled from red (high SAR value) to blue (low SAR values). It can be observed that the inhomogeneous tissue distribution of the visible human phantom has a big impact on the local SAR values.

Especially the region of the pinna shows high SAR values. Nevertheless it seems that the SAM gives a conservative estimation of the absolute maximum.



a) SAM phantom: $\max(SAR_{1g}) = 7.5$ W/kg. b) Visible Human: $\max(SAR_{1g}) = 5.4$ W/kg. c) SAM phantom: $\max(SAR_{1g}) = 8.96$ W/kg. d) Visible Human: $\max(SAR_{1g}) = 7.65$ W/kg.

Fig. 4: SAR induced in the SAM phantom and the Visible Human model. Frequency f = 835 MHz (a,b) and f=1900MHz (c,d), cheek position, 1g averaging.

A comparison of the SAR distributions from 835 MHz and 1900 MHz shows a larger penetration depth into the human head at the lower frequency. The maximum SAR values are at 1900 MHz (8.96 W/kg) about 20% higher than at 835 MHz (7.65 W/kg).

VII. CONCLUSION

New procedures for the numerical computation of the SAR induced by mobile phones in the human head are defined and are currently evaluated using different field solvers. The standardization of these procedures intends to optimize the inter-comparison of investigations performed by different research groups. IMST takes part in the standardization and the evaluation of the procedures to ensure that these useful and necessary algorithms will be promptly implemented in the EMPIRE™ field solver and will reflect the latest state of the art. The comparison of the two investigated phantoms tend to show that the SAM phantom gives a conservative estimation of the calculated SAR value if it is compared to the inhomogeneous human head model.

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