Numerical Dosimetric Assessment using the FDTD Method

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Abstract

Different European and international standards (e.g. ICNIRP guidelines, ANSI C95.1 standard, European Council Recommendation) define basic restrictions and reference levels for human safety in electromagnetic fields. In order to check compliance between electronic equipment and basic restrictions in human safety standards additional standards exist that specify more detailed requirements for the testing. Most of these standards are based on measurements, e.g. the European standard EN 50361 for safety of mobile phones. However there is a growing number of standards that specify requirements for numerical methods, e.g. the European standard EN 50357 for devices used in radio-frequency identification, electronic article surveillance and similar applications.

This paper lists today's possibilities and limitations in numerical dosimetric assessment by showing a variety of applications. Since numerical dosimetric assessment can be used is a very early stage of development the examples are not limited to strict compliance testing but also to get a better insight in physical phenomena such as coupling mechanisms between the electronic device and the user. Special attention is given to the validation of the software and the phantom models of the human body and the influence on the results.

1 Introduction

With the growing use of RF and LF electronic equipment possible health risks related to the exposure to the electromagnetic field have become a critical point of discussion. In order to prevent from physical health impact, international standards [1] [2] [3] limit the exposure to such fields based upon known biological effects in a wide frequency range.

Most of these standards have in common that the restrictions are based on electrical parameters that have a direct link to a physical effect in the biological tissue. E.g. the SAR (Specific Absorption Rate), which is calculated from the electric field in the tissue, is linked to a temperature rise in the tissue. This temperature rise has to be limited in order to prevent physical damage. The disadvantage, at this point is, that it is often hardly possible to measure the electric field in the tissue of a person.

Two different approaches can be observed to treat this problem: On the one hand, with respect to mobile phones the European standard EN 50361 [4] enforces measurements of the SAR in a simplified phantom of the human head homogeneously filled with tissue simulating liquid when the mobile phone is attached to the phantom. On the other hand the European standard EN 50357 [5] enforces numerical simulations of the relevant parameters using a detailed numerical representation of the human body for the compliance testing of article surveillance systems. Other standards and protocols for computational comparisons are under development (e.g. [6]) at the moment and will enlarge the basis for numerical dosimetric assessment in the future.

This recent acceptance of numerical dosimetric simulations is based on the progress made in numerical calculation methods as well as computer hardware in the last years. With this regard much attention is paid to the Finite Difference Time Domain (FDTD) method.

This paper gives an overview on topics which can be efficiently treated by numerical dosimetric assessment. The observed range covers compliance testing as well as numerical analysis which helps to get a better insight in physical phenomena such as coupling mechanisms between the electronic device and the user. The applications described start in the low frequency range (50 Hz), cover standard frequency bands used by GSM telecommunication equipment and follow up to W-band used for the satellite communication [7]. The phantoms used are numerical representations of standardised homogeneous mannequins which, as well as voxel based phantoms built from data gained from tomographical analysis of humans. For special applications generic models are set up using material parameters from biological literature. Validations by means of analytical verifications using canonical configurations or comparisons with measured data are provided.

2 Numerical Method

2.1 FDTD Method

In this investigation the commercially available electromagnetic field simulator EMPIRE™ is used [8] to calculate induced fields in homogeneous and inhomogeneous models of the human body. EMPIRE™

applies the Finite Difference Time Domain (FDTD) method in order to solve Maxwell's equation for a given initial boundary problem [9]. Figure 1 shows the arrangement of electric and magnetic field components in a so called Yee-cell. Please note that the field components are not defined at the common point in centre of the cell, but are arranged in a way that enables a simplified calculation of the curls in Faradays and Amperes law.

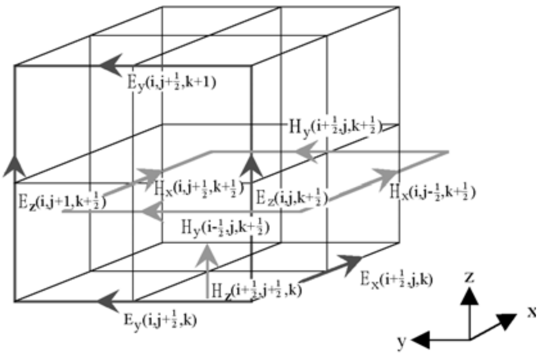

Fig. 1: Arrangement of electric and magnetic field components in a Yee-cell.

2.2 Human body models

Figure 2 shows the inhomogeneous body model from Air Force Research Laboratory (AFRL) [10].

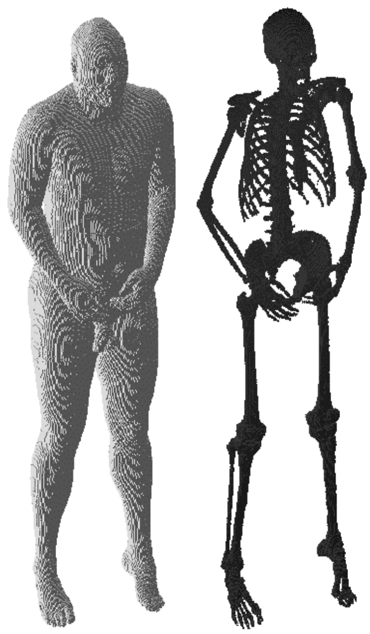

Fig. 2: AFRL body model.

The model is available on the internet in three different spatial resolutions ranging from 1 mm to 3 mm. The model consists of 40 different biological tissues. The dielectric properties of the different tissues are given from in the frequency range from 10 Hz up to 100 GHz by a parametric model.

Figure 3 shows the homogeneous SAM phantom for mobile phone compliance testing according to EN 50361 [4].

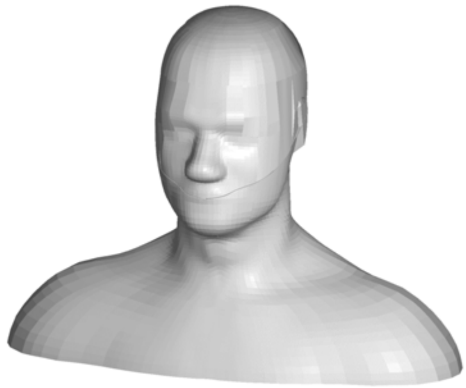

Fig. 3: SAM phantom.

Figure 4 shows an homogeneous ellipsoid model for compliance testing according to EN 50357 [5]. This standard provides two options of human body models. Besides anatomically based human body models the use of ellipsoid models is possible. There are two ellipsoid models defined with different size in order to represent the human head and trunk.

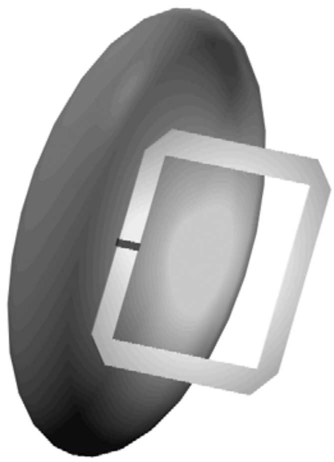

Fig. 4: Ellipsoid model and model of an RFID coil.

2.3 Spatial averaging

The human safety standards require spatial averaging of the current density and specific absorption rate in the human body. The current density has to be averaged of an area of 1 cm² and the specific absorption rate has to be averaged over a mass of 10 g according to the European Council Recommendation [2] or over a mass of 1 g according to ANSI [3]. The volume for SAR evaluation has to be cubical in shape. In the case of curved boundaries of the human body models different averaging algorithms are under consideration. Figure 5 show two methods. In the first case the cube is completely inside the body. In the second case the size of the cube is enlarged until the mass inside the cube is 1 g or 10 g, respectively. Another methods distort the cube in one Cartesian coordinate in order to align the "cube" to the surface. However at curved boundaries the cube averaging method can not be applied directly and a modification of the volume is nec-

necessary. Of course the choice of the averaging method has an impact on the result.

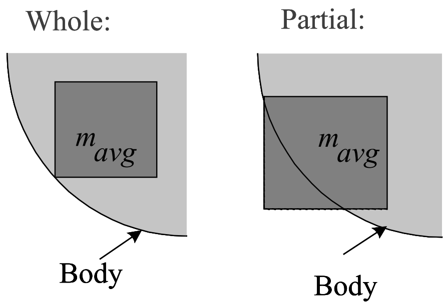

Fig. 5: Averaging methods at curved boundaries.

2.4 Validation

Validation is a crucial point in numerical dosimetric assessment. Two aspects have to be considered. First the model of the device under test has to be accurate. This can be demonstrated by comparison of simulated and measured electric or magnetic near field distribution. Second the software must be able to evaluate the basic restriction according to the human safety standard. Therefore special averaging mechanisms must be implemented and tested carefully. This evaluation of the software can be done by comparison of simulated averaged values against analytical results or by comparison against measurement results from established measurement systems. E.g. concerning the assessment of specific absorption rate from mobile phones the dosimetric system DASY from Schmid and Partner Engineering AG (SPEAG) represents an established standard which can serve as a reference for the numerical method.

3 Applications

3.1 Mobile Phone

Dosimetric compliance testing of mobile phones requires the assessment of the maximum SAR (averaged over 1 g of tissue according to [3] or 10 g of tissue according to [2]) in the head of the SAM phantom (Figure 3). According to[4] this assessment has to be done by measurement, - it is not allowed to use numerical simulations for compliance testing. However, numerical simulations can help to optimise the interaction between the mobile and the user in an early stage during the development phase of the mobile. Moreover, numerical dosimetric procedures offer better insight in the physical phenomena involved.

Figure 6 shows the SAR distribution in the head of the SAM phantom when it is exposed by a mobile phone operating in the GSM900 standard. The numerical simulation has been performed using EMPIRE™ FDTD software. The complete simulation run takes 4 hours on a 2 GHz Pentium 4 processor. It requires about 500 MB RAM.

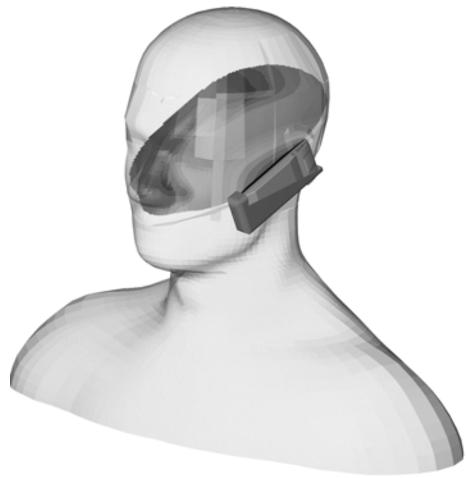

Fig. 6: EMPIRE™ Simulation of the SAR distribution in the head of the SAM phantom.

Figure 7 displays the maximum 10 g averaged SAR along the axis of the mobile phone before and after the optimizations process.

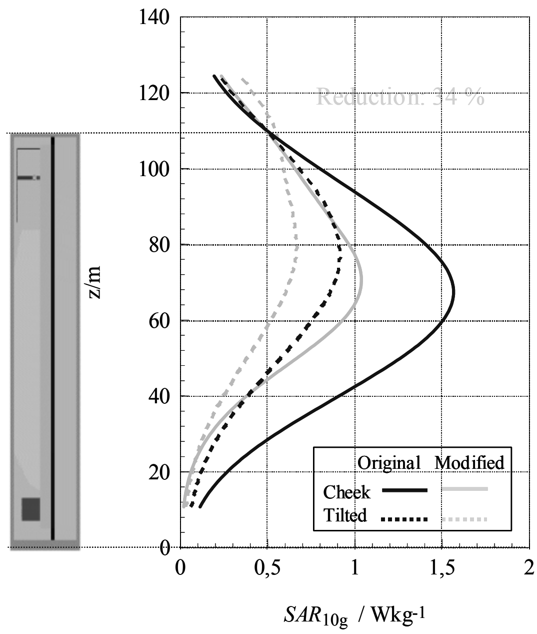

Fig. 7: Maximum SAR along the axis of the mobile phone in the head of the SAM phantom.

The optimization has been performed for the GSM900 frequncy range. It can be observed that the maximum SAR is not related to currents on the antenna module but occurs relative to curents on the mobile phone itself. The optimization method accounts for this behaviour and is described in more detail in [11].

Due to the increasing use of numerical dosimetric investigations, an IEEE standard for the correct procedure to be followed when using a numerical representation of the SAM phantom is under constuction at the moment [6].

3.2 RFID Device

A numerical dosimetric application of an RFID device consists of a coil that generates a magnetic field in its vicinity. Figure 8 shows the winding of the rectangular shaped coil. In a first step the numerical model of the device has been validated by comparing the simulated near field against the measured near field on the main axis of the device. Figure 8 shows the current density results in the ellipsoid model. Finally, the current density has been averaged and compared to the basic restriction in the human safety standard.

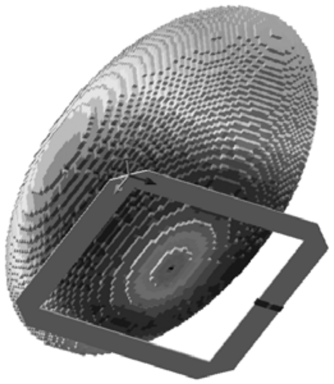

Fig. 8: Current density results in the ellipsoid model and model of an RFID coil.

3.3 Human in electric field at power line frequencies

The inhomogeneous human body model shown in Figure 2 is placed in vertical electric field at power line frequencies. Figure 9 shows the maximum current density induced in the body in comparison to simplified analytical models and a homogeneous body model.

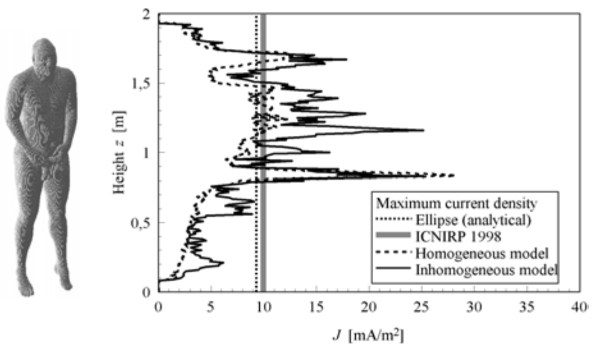

Fig. 9: Maximum current density induced in the human body in a vertical electric field at 50 Hz.

The homogeneous electric field has been generated by two plane waves that interfere in order to cancel the magnetic field component. A special low frequency algorithm based on a quasi-static approach has been implemented into EMPIRE^{TM} for this purpose. It uses the approach that at low frequencies the displacement current is much smaller than the conduction current. Using this algorithm speeds up the simulation time significantly.

4 References

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