

Electrical Energy Absorption in the Human Head From a Cellular Telephone

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Abstract

The antenna of a cellular telephone in close proximity to the human head for a variety of time periods raises questions. This research uses finite-difference time-domain (FDTD) method to calculate the power deposition from a cellular telephone on a high-resolution model of a human head as measured by the specific absorption rates (SAR) in W/kg. Visualization has been used to verify the modeling for simulation, assisted in analyzing the data and understanding the physical aspects controlling the power absorption.

The visualizations verified both the head data and the phone position relative to the head data for the simulation. In addition, the visualization of the head data with the superimposed SAR simulation was viewed as slices. These slice images connected visually with previous research results viewed as slices. Lastly the head data and SAR were viewed as a volume which provided a better understanding of the physical relationship between SAR and head data, as well as, providing a more human context for the research.

1. Introduction

Recently there has been considerable public interest, as well as corporate interest in the influence of cellular telephones on the human head [References 1, 2, & 3]. The work reported here investigates this sensitive issue.

The finite-difference time-domain (FDTD) method is used to calculate the power deposition from a cellular telephone for a model of a human head measured by the specific absorption rates (SAR) in W/kg. The high-resolution model was developed from MRI scans from an adult. Scaling of this adult model approximates models of a 10-year old and 5-year old child. Visualization offered an opportunity to understand the underlying physical effects that are controlling this power deposition.

First there was a visualization of a phone and its orientation with the head model. Second there was a visualization of different tissue types in the head (Figure 1). Third there was a visualization of the SAR superimposed on slices through the head tissues (Figure 2). Fourth there was a visualization of the head tissues and the SAR as a volume (Figures 5 & 6).

2. Research

Recent public concern and increasing federal regulation have spawned huge industrial interest in software which can quickly and accurately determine the performance of cellular telephones and other personal communication systems (PCS). This analysis requires extremely high-resolution analysis of the PCS device in close proximity to the anatomically-based models of the human body. The finite-difference time-domain (FDTD) method is used to calculate the power deposition from the telephone for a 1.974x1.974x3 mm resolution model of the human head as measured by the specific absorption rates (SARs) in W/kg. This high-resolution model of the head was developed from the MRI scans of an adult male volunteer. Approximate models of 5- and 10-year old children were developed by scaling this adult model to correspond to the heights and weights for such subjects. In all of these models, 15 tissue types were identified, and the electrical properties of these tissues were taken from in vivo and in vitro measurements. To represent a realistic position for holding the telephone, the ear was pressed against the head, and the phone was held in direct contact with the ear. A "generic" model of a cellular telephone is

used for these studies. It is a 6x3x15 cm metal box, covered with plastic, with a quarter-wave monopole antenna, also covered in plastic, mounted on the top back corner. Due to the sheer magnitude of the model, visualization is essential to verify and modify the orientation of the phone relative to the head.

The quantity of output data from the FDTD simulation is enormous. Magnitude and phase of the vector electric and magnetic fields at every location in the head model (and outside, as well) is obtained, and the magnitudes of the electric fields are used to calculate SAR (W/kg) in each voxel of the head model. Before we used visualization, numerous attempts were made at developing a partial understanding of the coupling phenomenon and what was controlling the SAR distribution, particularly in the ear region, where there values were the highest, etc. Visualization offered us the opportunity for the first time to understand the underlying physical effects that are controlling this power deposition.

3. Visualization

The goal of this visualization was to provide the researcher with a view of a simulation as it occurred in the tissues of the human head. This goal was achieved in four incremental steps. Previous visualization work had developed a color map that was effective for the portrayal of continuous values of an SAR simulation.

The first step was to verify the accuracy of the MRI-based head model using SGI Iris Explorer visualization software. This verification was achieved by displaying iso-surfaces of the tissues. The skin data of the human head was displayed as a 0 Dimensional Lattice or a set of points. This combined display provided a surface view of tissues, such as the brain, through the context of the skin as points. This allowed for a verification of the relative location of each tissue type could be observed within the skin of the human head. Each tissue type was given a small ramp of colors within a single color map for all the interior tissues and the skin.

The second step was to visualize the orientation of the telephone next to the head. Early phases of this simulation illuminated errors in the modeling, thus this visualization prevented the running of erroneous simulations.

The third step was to view the SAR distribution on cut planes (Figures 2). As in the first step, the skin was portrayed as a set of points displayed with the cut planes. In order to display both tissues and SAR on the cut plane the color map was partitioned into two sections (Figure 3). The first 32 colors were reserved tissue types, so that the tissues would appear as single value poster type colors. The remaining colors of the color map were used for the continuous SAR values. The color map developed in earlier work with this research was scaled to fit the 223 colors, instead of 256 and translated up to reside in the 32nd to 255th location of the color map.

The head data and the SAR data were quantized to a byte and merged into a single file of bytes. This type of file was created for cut plane slices for the three orthogonal cross sections of the head, that is from front to back, top to bottom and side to side. A second Iris Explorer map was created to display the skin as a point set and any combination of the three cut-planes. Displays of three individual cut planes, three pairs of cut planes and all three cut planes were used to view the result of the SAR simulation.

The fourth step had two parts. The first part was to view the tissues of the head as a volume (Figure 1) and the second part was to view the head and simulation as a volume (Figures 5 & 6). The AHPCRC at the University of Minnesota volume rendering software BOB was used to display and interactively manipulate the display. BOB, as its name implies, works on a Brick Of Bytes. The cut plane data was concatenated into such a set of bytes. The color map from the previous visualization of the cut planes was used for the volume rendering. Volume rendering also uses an opacity mapping of the byte data. The low 32 locations of the opacity map were mapped to the head tissues and highly transparent (Figure 4). The remaining locations of the opacity map were used for the values of the SAR simulation. Ramping from a low opacity for low values of the SAR and high opacity for the high values of the SAR. This combination of color and opacity maps with volume rendering provided a view of the SAR simulation in the human head that was a quantum more realistic than previous displays.

BOB was used to do a simple animation where the display was slowly rotated (Stills from the Animation are seen in Figures 5 & 6). This animation is output as a large raw file. Utah Raster Toolkit (URT) procedure *rawtorle* was used to yield a large rle (run length encoded picture) file, URT procedures *rlesplit* output individual picture files and *rletorgb* was used to convert the rle files to SGI rgb image format files. SGI programs *moviemaker* and *movieplayer* were used to produce a smooth rotation of the SAR and head data. This smooth animation furthered the sense of a human connection with a human head displayed with an SAR simulation.

4. Observations

Being able to visualize the relative position of the telephone, its antenna, the head, and the SAR distribution shows the antenna designer that the major contribution to power deposition from this type of box-antenna configuration comes from the feedpoint of the antenna. It also is extremely useful for analyzing the location of peak SAR, which is seen in red. Instead of being on the outside of the ear, nearest the phone, it is generally seen where the ear is in contact with the head, either naturally or because of being pressed against the head by the phone. The dominance of power deposition in the ear also demonstrates the great importance of using a realistic, anatomically-based high-resolution head model such the one used here. Simpler models (numerical or experimental) which do not realistically model the ear are unable to correctly predict these details of the SAR distribution. In addition, the comparison of the adult and child models provides additional understanding of the effect the model has on the SAR distribution. The overall SAR distribution in these three models is seen to be reasonably similar except than a deeper penetration of the coupled electromagnetic energy is observed for the models of the younger subjects. The localized SAR distribution in the ear region is also seen to be significantly higher in the children than in the adult, assumably because the ear is smaller, and hence, the ear and head are proportionally closer to the antenna.

This visualization has been indispensable in ensuring accurate modeling for the simulations, assisting in analyzing the myriad of data, and

understanding the physical aspects controlling the power absorption.

5. Video

The video tape shows six SAR simulations in a Human Head Model for a Cellular Telephone, three at 835 MHz and the other three at 1900 MHz. The first three simulations show a rotational animation sequence for an adult sized head, a 10-year old sized head and a 5-year old head. Each animation sequence is preceded by a still showing an image of the head model and telephone model used in the simulation. Notice as the age of the human model gets younger the size of the telephone becomes relative larger. These three animation's are followed by a still frame comparing the three sized heads with their relative sizes represented. The first three animation's and still frames are for a phone at 835 MHz. This is followed by three rotational animation's with their head model and telephone model stills and a comparative still frame of an SAR simulation in a human head model for a cellular telephone at 1900 MHz.

6. Acknowledgments

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7. References

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- [3] V. Pandit, "Simulation & Visualization for Bioelectromagnetic Problems", MS., Dept. of Electrical Eng., University of Utah, 1996

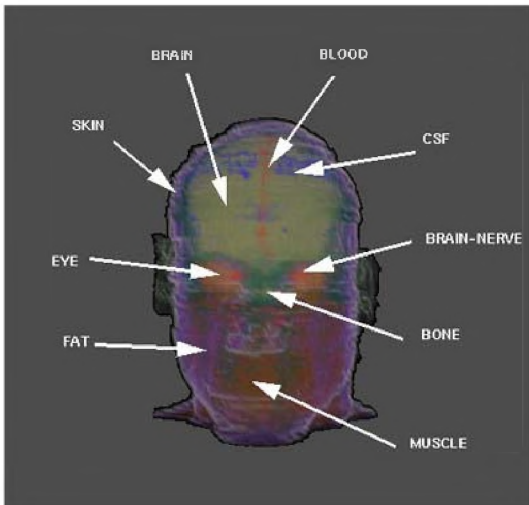


Figure 1: Tissues within Head Model

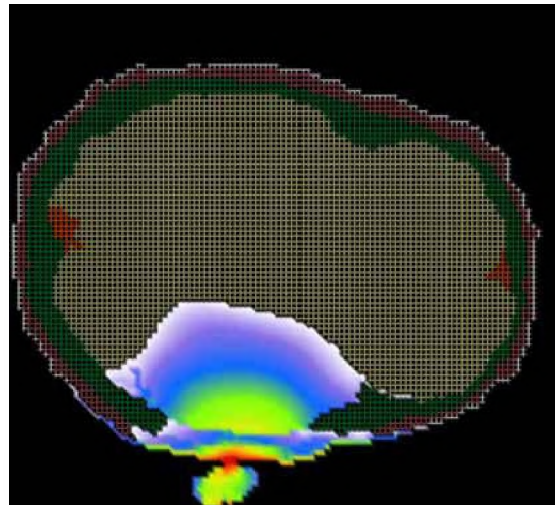


Figure 2: Tissues & SAR Simulation Cut Plane

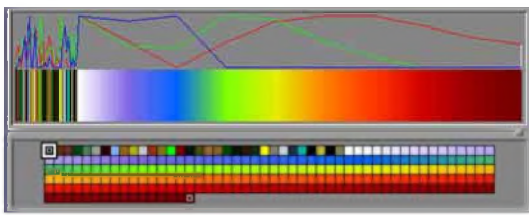


Figure 3: Color Map

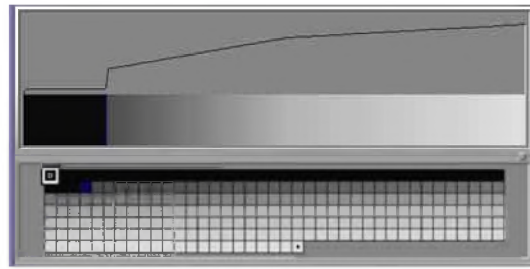


Figure 4: Opacity Map

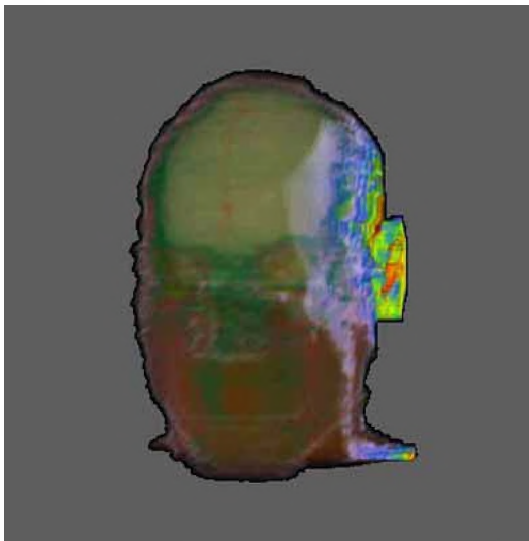


Figure 5: Tissues & SAR Simulation
(Front View)

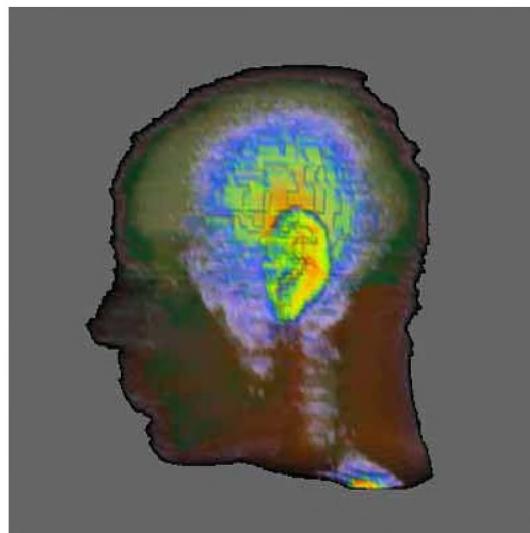


Figure 6: Tissues & SAR Simulation
(Left Side View)