FDTD COMPUTATION OF POWER DEPOSITION IN THE HEAD FOR CELLULAR TELEPHONES

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Abstract

The finite-difference time-domain method is used to calculate radiation pattern and specific absorption rate (SAR) in the human head due to cellular telephones. For realistic simulation of the ordinary positions of holding the phone, the ear of the model is pressed against the head, the head is tilted at an appropriate angle, and the hand is approximately represented. Cellular phones at frequencies of 835 and 1900 MHz are simulated with monopole above handsets with antenna lengths of $\lambda/4$ and 3 $\lambda/8$. The time-averaged radiated power of 600 mW is used for the 835 MHz test cases, and 125 mW is used for 1900 MHz. The importance of detailed modeling of the tissues is examined by comparing heterogeneous and homogeneous models, and the effect of realistically tilting the phone against the head is also examined. A novel method to truncate the head model to save computer memory is presented.

Millimeter-Resolution Head Model

The model of the head was developed from the MRI scans of an adult male volunteer with a resolution of 1.974 × 1.974 × 3 mm. Fifteen tissue types within the head (brain, cerebrospinal fluid, nerve, air cavities, muscle, fat, bone, cartilage, skin, eye humour, sclera, lens, pineal, pituitary, and parotid glands) were identified. The dielectric properties of each of these tissues were based on the 4-Cole-Cole equation fits to the recent measured data [1]. The head model is shown in Fig. 1.

Code Validation

The code was validated by comparing several progressively more realistic, numerical simulations with available analytical or experimental results. These simulations included a dipole antenna near a layered half space of bone and brain, near a plexiglass box filled with brain-simulating material, and near a sphere of brain material. More advanced tests included actual telephone models near cubes and spheres. Agreement between numerical and analytical or measured values was excellent.

Cellular Phone Simulations and the Importance of Heterogeneous Modeling

The "generic" cellular telephone was simulated as a dielectric-covered metal box of dimensions 2.96 × 5.73 × 15.5 cm ($14\ \delta_x$, $\times\ 28\ \delta_y \times 51\ \delta_z$) for the metal covered with 1-mm-thick plastic on all sides. Assumed for the radiators are $\lambda/4$ and 3 $\lambda/8$ monopole antennas mounted on the box. The calculated peak 1-g averaged SARs given in W/kg for the phone held straight (not realistically tilted) against the head are given in Table 1, column 1. The 3 $\lambda/8$ antennas were found to have significantly lower peak 1-g averaged SARs than the $\lambda/4$ antennas, and the 1900

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MHz phones generally had lower peak 1-g SARs than the 835 MHz phones, mainly because of the lower time-averaged power (125 mW rather than 600 mW at 835 MHz).

To examine the importance of detailed heterogeneous modeling, the heterogeneous 15-tissue model was compared to a homogeneous model of the same shape but with all voxels having the properties of brain. The SAR distributions of the two models are significantly different as shown in Fig. 2 for a cut through the location of peak SAR. The distribution of the homogeneous model is very smooth, whereas the distribution in the heterogeneous model varies significantly as affected by the variation of the electrical properties and specific gravity of the tissues. The difference in the distributions results in significantly different and higher peak 1-g SARs, as shown in Table 1, column 2. From the distribution patterns, it is apparent that any close agreement between the 1-g averaged SARs of the two models would be pure coincidence.

Table 1. Peak 1-g averaged SARs (W/kg) using an upright head model.

F (MHz)	Antenna	Heterogeneous model	Homogeneous Model
835	$\lambda/4$	2.93	4.17
	$3\lambda/8$	1.60	2.23
1900	$\lambda/4$	1.11	1.27
	$3\lambda/8$	0.69	0.88

Realistic Tilting of the Head

The effect of realistically tilting the phone against the head was also examined. When making an FDTD simulation on a rectangular grid, it is best to keep the antenna coincident with the grid, so when modeling a realistically tilted phone, the phone is kept straight, and the head is tilted. This is not trivial, since the original MRI scans were digitized on a rectangular grid with the head in a straight upright position. Two methods of tilting the head have been previously used. The first is to tilt the head when taking or digitizing the MRI scans, which results in a model with unadjustable tilt. The second method is to slide the layers forward, to represent tilt, but this makes a model that is significantly skewed. A more realistic tilt was obtained by mapping a tilted grid onto the original upright rectangular grid to obtain a realistically tilted model with tilts of any angle in any plane. Table 2 shows the effect of tilting the head on the 1-g averaged SAR values. The first column gives values for the phone held straight next to the head, in contact with the ear. The second column gives values for the phone tilted forward so that the mouth piece is opposite the mouth, but the phone is not in contact with the cheek. The third column represents the most realistic possible model for ordinary phone use, with the ear piece in contact with the ear, the mouth piece as near as possible to the mouth, and the phone in contact with the cheek. As the phone is tilted, the antenna becomes physically farther from the head, which reduces the peak 1-g SAR values. This is particularly evident for the longer antennas used at 835 MHz as compared to the shorter 1900 MHz antennas.

Conclusions

The finite-difference time-domain method was used to calculate the SAR distributions of cellular telephones at 835 and 1900 MHz next to the human head. A millimeter-resolution model developed from MRI scans was used. The importance of detailed heterogeneous models and the effect of realistically tilting the head were examined, and a new method to truncate the model to save computer time was presented.

References

1. Camelia Gabriel, personal communication, November 1995.

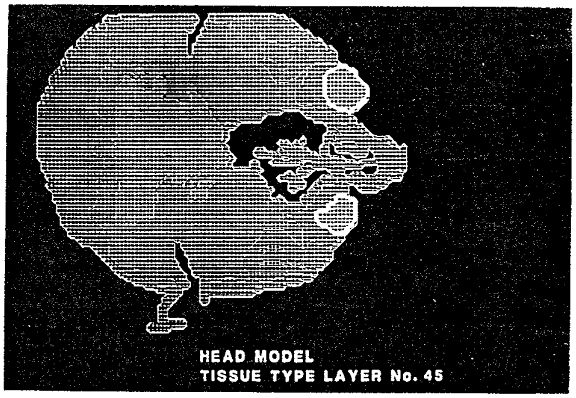

Fig. 1. Layer through the eye of the MRI-based MRI-based model of the head with resolution 1.974 × 1.974 × 3 mm.

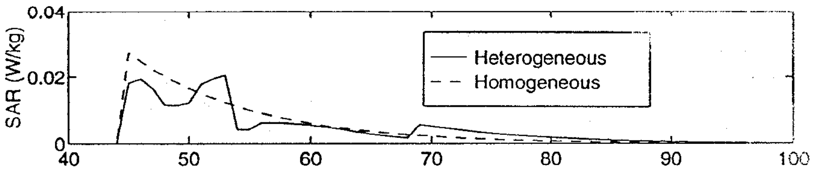

Fig. 2. SAR distribution along an ear-to-ear cut of the model for heterogeneous and homogeneous models.

Table 2. Peak 1-g SAR (W/kg) values for realistically tilted telephones.

Frequency (MHz)	Antenna	Untilted Model	Forward Tilt (30°)	Forward Tilt (30°) Side Tilt (9°)
835	$\lambda/4$	2.93	2.44	2.31
	$3\,\lambda/8$	1.60		
1900	$\lambda/4$	1.11	1.08	1.20
	$3\,\lambda/8$	0.69		

Truncation of the Model to Reduce Memory Requirements

To improve the efficiency of these calculations, a novel method of truncating the model on the side of the head away from the telephone was used. A first simulation was performed with a Perfect Magnetic Conductor (PMC) at the truncation plane, and a second simulation was performed with a Perfect Electric Conductor (PEC) at this plane. The complex fields from the two simulations were stored and added together to give a superposition of these two simulations. This is equivalent to symmetrically copying the head model around the plane of truncation, and placing a second, unfed telephone symmetrically opposite the first. This truncation method will give exactly correct results if the two telephone models do not couple and if the field distribution has decayed sufficiently before it reaches the truncation plane. Correlation of the SAR distributions between the simulation with the full model and simulation with 1/2 and 1/3 of the model are excellent as shown in Table 3. This method saves up to 50% of the computer memory requirements, while requiring minimal additional computer time.

Table 3. Peak 1-g averaged SARs in full and truncated models (correlation coefficients for the complete SAR distributions are given in parentheses).

Frequency (MHz)	Antenna	Full Head Model	Half Head Model	1/3 Head Model
835	$\lambda/4$	2.93 (1.00000)	2.86 (.9994804)	2.84 (.9961399)
	$3\,\lambda/8$	1.60 (1.00000)	1.62 (.9965456)	1.80 (.9891098
1900	$\lambda/4$	1.11 (1.00000)	1.10 (.9999852)	1.10 (.999912)
	$3\,\lambda/8$	0.69 (1.00000)	0.68 (.9996114)	0.69 (.9994331)
Memory (Mbytes)		180	109	89