Polarization and Human Body Effects on the Microwave Absorption in a Human Head Exposed to Radiation from Handheld Devices

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***Abstract*—A multigrid finite-difference time-domain code was used to calculate specific absorption rate (SAR) distribution in a human head exposed to microwave radiation from handheld antennas. The effect of the human body was taken into account and different antennas and polarization conditions were considered. The distance between the antenna and human head were varied to examine the effect of the human body on the SAR distribution. From the numerical results, it is shown that the human body plays a significant role on the SAR value and its distribution in the head [as high as 53% monopole, 41% planar inverted F antenna (PIFA)]. It is also shown that the effect of the body is more dominant at lower frequencies (monopole 900 MHz versus 1.9 GHz). For the monopole case, effect of body is particularly important at larger separation distances from the head, e.g., at $d = 4$ cm versus $d = 0.5$ cm. Effect of body is particularly important for the vertical orientation cases for both the monopole and PIFA.**

***Index Terms*—Biological effects, EM radiation, FDTD calculations, handheld devices, polarization effects.**

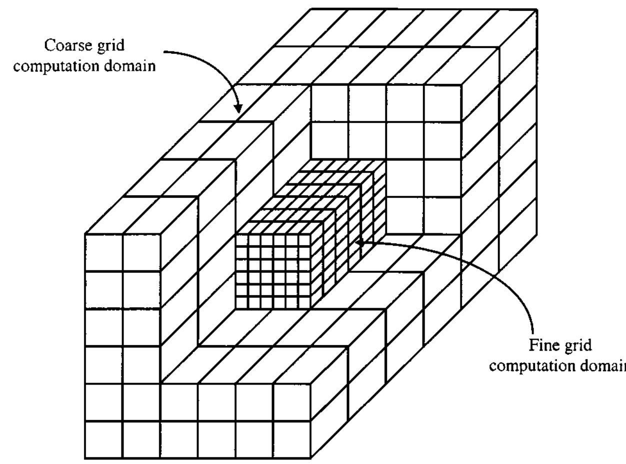

Fig. 1. Coarse- and fine-grid structure in the multigrid FDTD calculations.

I. Introduction

Several research groups have examined the specific absorption rate (SAR) values in the human head when exposed to microwave radiation from handheld devices [1]–[5]. Exposures to radiation from various types of antennas were considered, and effect of frequency, separation distances, etc., were examined. Furthermore, the radiation characteristics of various types of antennas were evaluated and the effect of the human head on the antenna performance was studied [1]. In all cases, however, an isolated human head was modeled and included in the simulation. It is of interest, however, to examine the effect of the human body on the RF absorption by the human head and determine the conditions under which it is necessary to take the effect of the human body into account in these calculations. It is the objective of this paper to study such an issue and quantify the effect of the human body on the SAR values and the distribution in the head. With the development of the multigrid finite difference time domain (FDTD) [6]–[9], it is possible to provide accurate modeling of the various tissue types in the human head and, at the same time, take into account the effect of the human body. In this paper, simulation results using the multigrid FDTD will be reported and discussed. Specifically, the FDTD grid may be used to provide accurate SAR distribution in the head, while a coarse FDTD grid will be used to model and take into account the effect of the human body.

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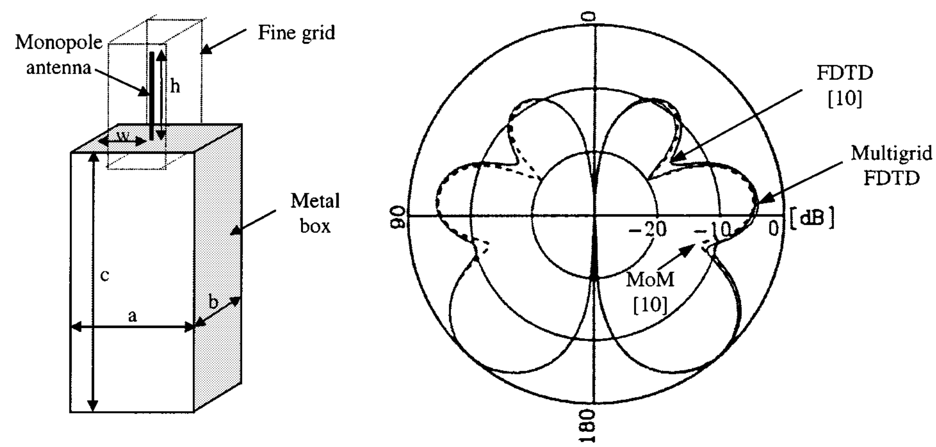
II. Multigrid FDTD

FDTD is a powerful technique for analyzing electromagnetic problems of complex geometry. Nevertheless, difficulties will arise in using FDTD when, for example, modeling circular structures or when modeling electrically large geometries with small-scale structures (biological effects of cellular phones on human heads). This is due to the fact that increasing the resolution by n in a three-dimensional (3-D) uniform-grid FDTD simulation increases the memory requirements by n^3 and the time required for simulation by n^4. It is, therefore, difficult, or even impossible, to obtain detailed results because of the limited computer resources.

The multigrid FDTD developed at the University of Utah, Salt Lake City, proved helpful in simulating electrically large geometry [6]–[8]. It is efficient and memory saving while obtaining satisfactory simulation accuracy. In multigrid FDTD, two regions are created: the coarse- and fine-grid regions. The coarse-grid region contains the entire structure and the fine-grid region is placed to surround structures of interest, as shown in Fig. 1.



(a) (b)

Fig. 2. (a) Fine-grid region was placed around the monopole antenna and cut some portion of the metal box, while the metal box was placed in a coarse-grid region. (b) Obtained radiation patterns of the monopole antenna.

TABLE I
PROPERTIES OF THE TISSUES IN THE FDTD MODEL: 900 MHz

	Bone	Brain	Muscle	Eyeball	Fat	Skin	Lens
Dielectric constant	9.67	52.7	59.1	80.0	4.67	59.1	59.1
Conductivity [S/m]	0.0508	1.05	1.26	1.90	0.0583	1.26	1.26

TABLE II
PROPERTIES OF THE TISSUES IN THE FDTM MODEL: 1900 MHz

	Bone	Brain	Muscle	Eyeball	Fat	Skin	Lens
Dielectric constant	7.75	46.0	55.3	80.0	9.70	59.1	55.3
Conductivity [S/m]	0.105	1.65	2.0	1.90	0.270	1.26	2.0

The fine-grid cell size is set as an integer fraction of the coarse-grid cell ($\mathrm{nfact} = \Delta\ell_c/\Delta\ell_f$ where nfact is the integer refinement factor and $\Delta\ell_c$ and $\Delta\ell_f$ are the coarse- and fine-grid sizes, respectively). For stability, the time increment in the fine grid is also reduced from the coarse-grid time increment by the same integer.

To show the validity of the multigrid FDTD for the calculation of antenna radiation problems, the radiation pattern of a monopole antenna on a conducting box was calculated. The geometry of antenna is similar to the antenna in Fig. 2(a). To compare our results with those published in the literature [10], the sizes of the antenna were selected as $a = 60$ mm, $b = 10$ mm, $h = 50$ mm, $w = 30$ mm, and $c = 200$ mm. The operating frequency was 1.5 GHz. A fine-grid region was constructed around the monopole, with $\mathrm{nfact} = 5$ [see Fig. 2(a)]. The results are shown in Fig. 2(b). As can be seen, the obtained results were in good agreement with those published earlier [10].

III. SIMULATION MODELS

1) Head Model: Anatomical human features were modeled within the FDTD framework by mapping the spatial location of the different tissues into a permittivity and conductivity assignment in the computational grid. A fine grid with a 2.45-mm spatial resolution was used for the human head, resulting in a grid with $100 \times 100 \times 100$ fine grid cells. The basic parts constituting the human head are shown in Fig. 3. The dielectric and conductivity of the tissues in the human head model are given in Tables I and II for 900 and 1900 MHz, respectively.

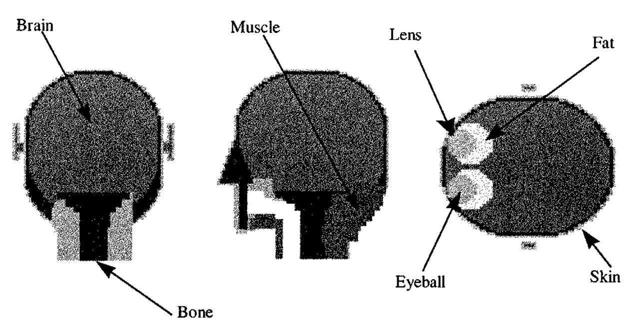


Fig. 3. Human head model. A fine-grid computation domain was used for modeling the head.

2) Body Model: The body was modeled using a coarse-grid region in the multigrid FDTD simulation. The size of the cubic

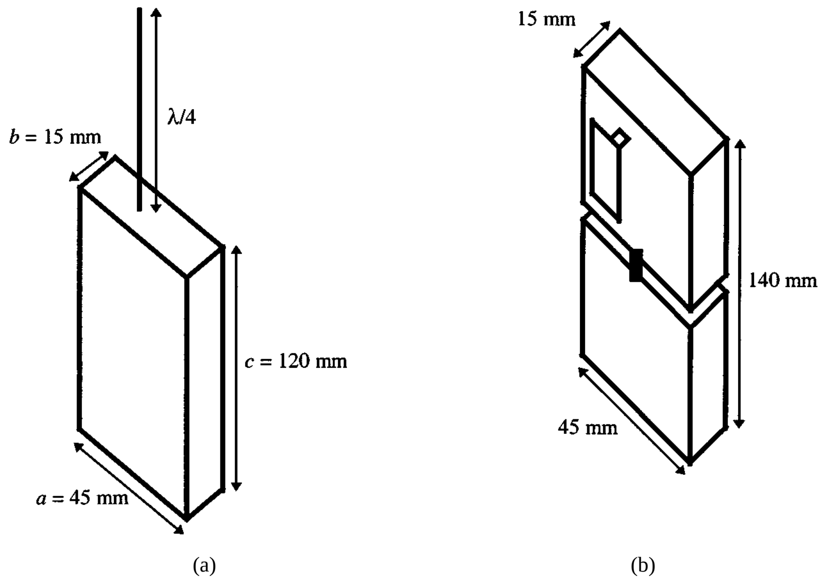


Fig. 4. Antenna models used in the multigrid FDTD simulation.

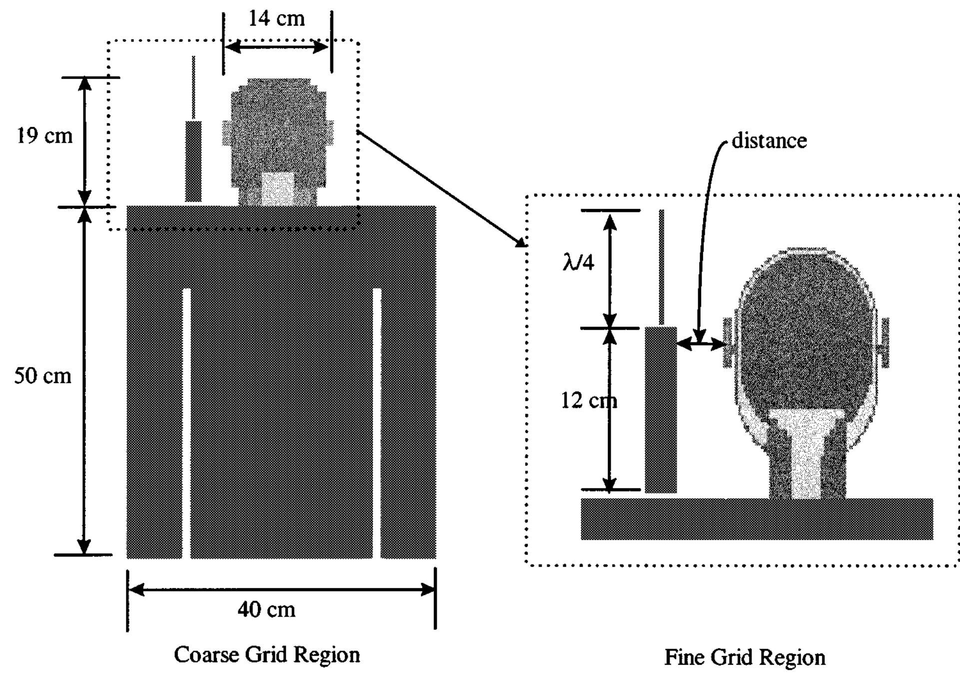
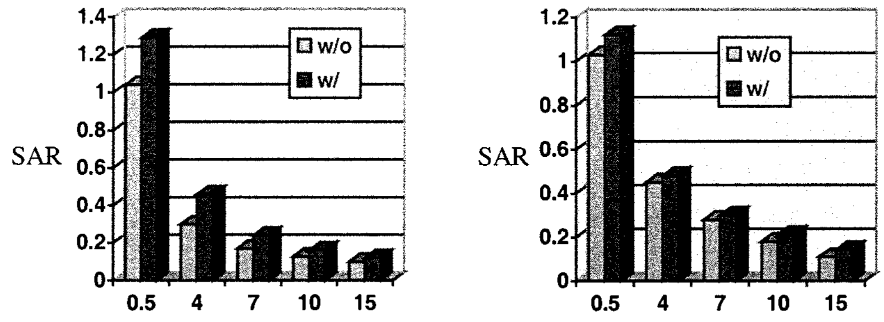


Fig. 5. FDTD regions in the multigrid FDTD simulations.

TABLE III
TOTAL SARs IN THE HUMAN HEAD: VERTICAL POLARIZATION

Distance (cm)	Frequency					
	900 MHz			1900 MHz		
	w/o	w/	increase (%)	w/o	w/	increase (%)
0.5	1.04	1.29	24	1.03	1.12	8.7
4.0	0.30	0.46	53	0.45	0.48	6.7
7.0	0.17	0.24	41	0.28	0.30	7.1
10.0	0.13	0.16	23	0.18	0.21	17
15.0	0.099	0.12	21	0.11	0.136	24

cell was four times larger than the fine grid cell, i.e., 8.9 mm. The dielectric constant of the body tissue was assumed to be homogeneous with relative permittivity equal to 2/3 the value for muscle tissue [11]. The conductivity is the same as muscle.

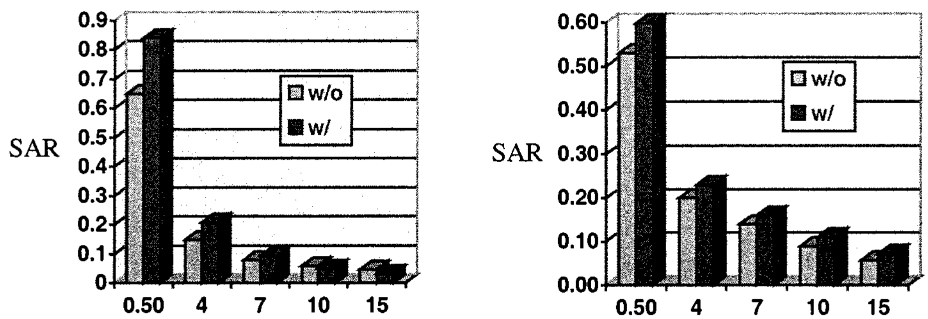


(a) (b)

Fig. 6. Total SARs in the human head: vertical monopole antenna. (a) $f = 900$ MHz. (b) $f = 1900$ MHz.

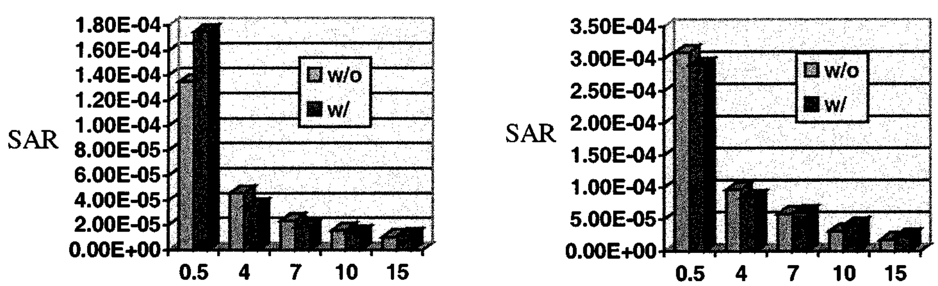
TABLE IV
TOTAL SARs IN THE HUMAN BRAIN AREA: VERTICAL POLARIZATION CASE

Distance (cm)	Frequency					
	900 MHz			1900 MHz		
	w/o	w/	increase (%)	w/o	w/	increase (%)
0.5	0.65	0.84	29	0.53	0.597	13
4.0	0.15	0.21	40	0.20	0.23	15
7.0	0.08	0.094	18	0.14	0.16	14
10.0	0.059	0.051	-14	0.089	0.11	24
15.0	0.046	0.032	-30	0.058	0.072	24



(a) (b)

Fig. 7. Total SARs in the human head: vertical monopole antenna (a) $f = 900$ MHz. (b) $f = 1900$ MHz.



(a) (b)

Fig. 8. Maximum SARs in the human head: vertical monopole antenna. (a) $f = 900$ MHz (b) $f = 1900$ MHz.

3) Antenna Models: Two antenna types were examined in this paper. The first is a monopole over a metal box, as shown in Fig. 4(a). The second is a planar inverted F antenna (PIFA), as shown in Fig. 4(b). The sources of both antennas in the FDTD are implemented as hard sources.

4) FDTD Simulation Region: Fig. 5 shows the two complete FDTD simulation regions of the human head, including the human body.

IV. RESULTS

The human body effect on the absorption in the human head as a result of exposure to radiation from handheld devices will be examined next. The distance between the metal box holding the antenna and the human head (Fig. 5), the polarization of the antennas, and the frequency were varied, and the resulting SAR values were calculated. Results will be presented for both monopole and PIFA antennas.

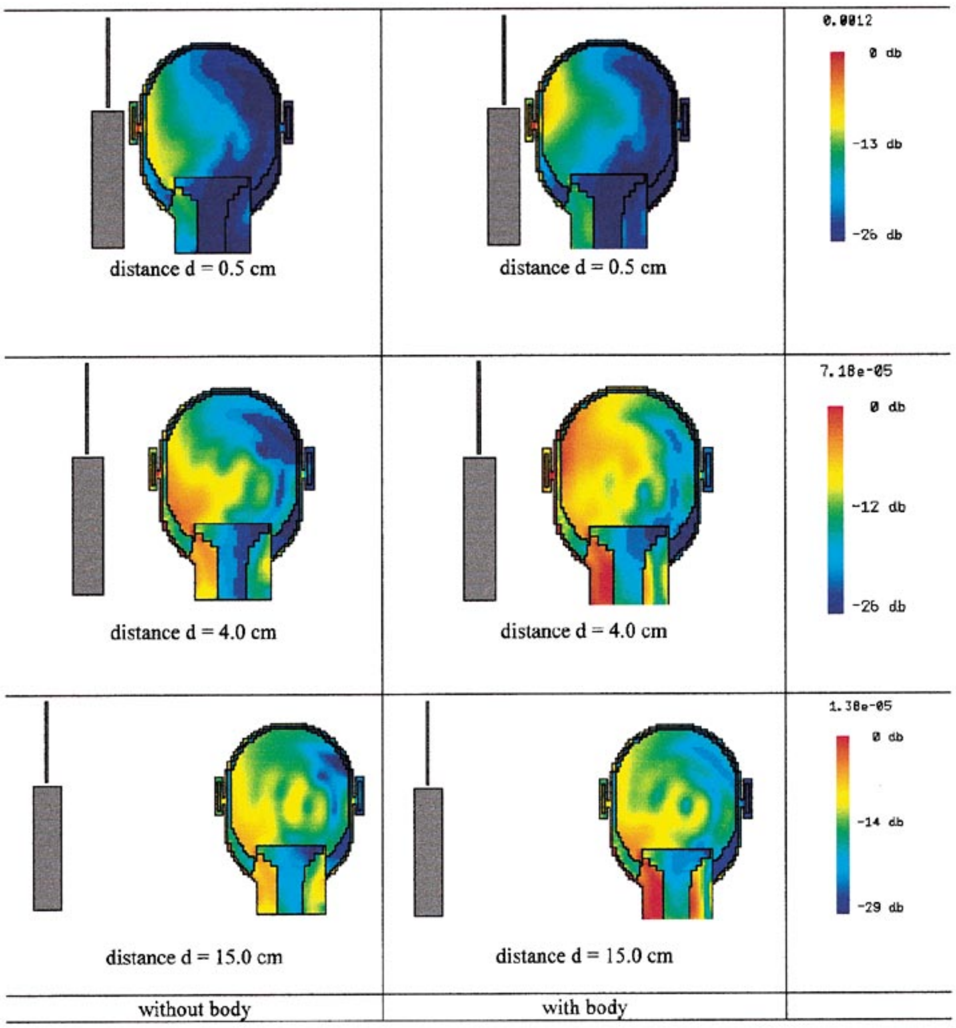


Fig. 9. Vertical cross sections of the human body showing SAR distributions for vertical monopole antenna at 900 MHz with and without body.

TABLE V
MAXIMUM SARS IN THE HUMAN BRAIN: VERTICAL POLARIZATION

Distance (cm)	Frequency					
	900 MHz			1900 MHz		
	w/o	w/	increase (%)	w/o	w/	increase (%)
0.5	1.35×10^{-4}	1.75×10^{-4}	29	3.1×10^{-4}	2.9×10^{-4}	-7
4.0	4.58×10^{-5}	3.55×10^{-5}	-22	9.7×10^{-5}	8.4×10^{-5}	-13
7.0	2.36×10^{-5}	1.83×10^{-5}	-22	5.9×10^{-5}	6.0×10^{-5}	2
10.0	1.57×10^{-5}	1.39×10^{-5}	-11	3.2×10^{-5}	4.1×10^{-5}	28
15.0	1.05×10^{-5}	1.15×10^{-5}	10	1.8×10^{-5}	2.4×10^{-5}	33

A. Monopole Antenna, Vertical Polarization

Two values of working frequencies were considered in these calculations. Table III shows the SARs in the human head when the monopole antenna was vertically polarized. In this table, "w/o" refers to the case of without body, "w/" means with body, and "increase (%)" represents the percent increase in SAR values when body is present, compared to the case of without body. It should be noted that all SAR values were relative values and resulted from voltage excitation with constant magnitude at the antenna feed. This is justified because we are concerned only with the changes of the SARs due to the presence of the human body. Fig. 6 also shows the obtained SAR values as function of the distances between the antenna and human head.

The total SARs in the brain area were also calculated with and without the effect of the human body. The obtained results are given in Table IV and Fig. 7.

The maximum values of the SAR are also of importance in evaluating the safety from radiation devices. The maximum SAR values in the human brain were also calculated and the results are listed in Table V.

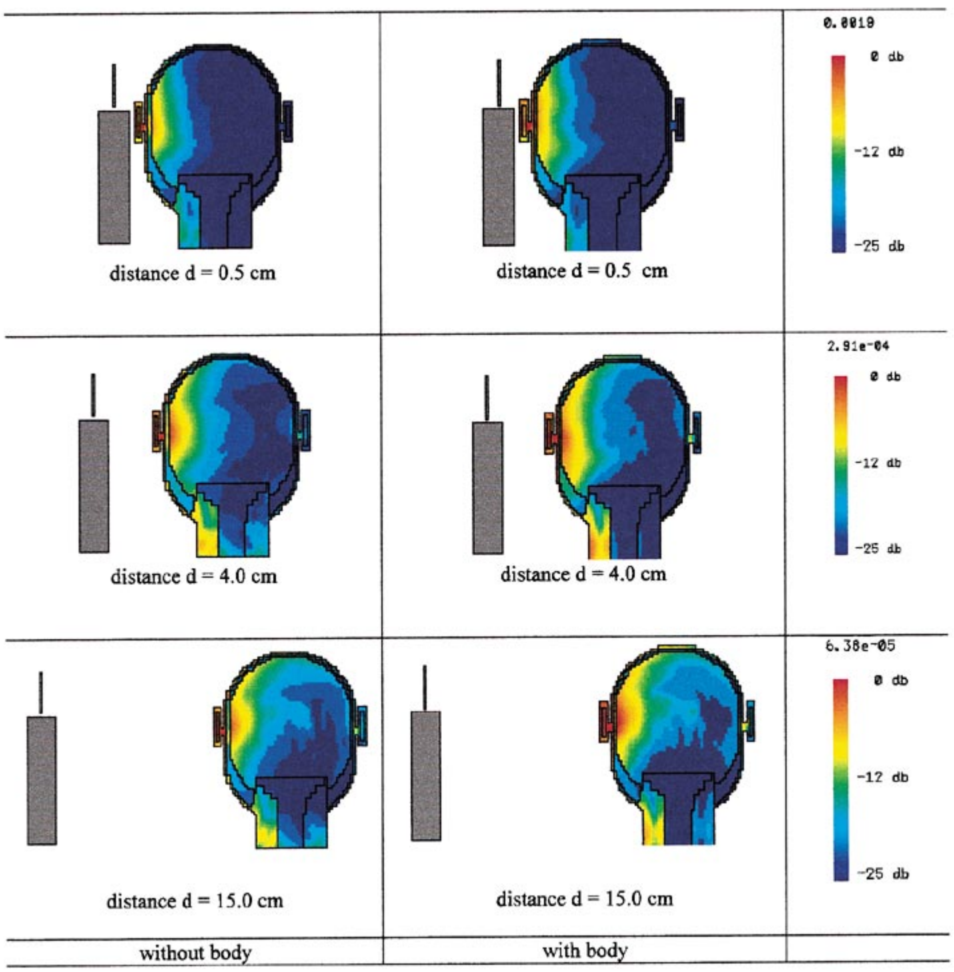


Fig. 10. Vertical cross sections of the human head illustrating SAR distributions for vertical monopole antenna at 1900 MHz with and without body.

TABLE VI
SARs IN THE HUMAN HEAD: $f = 900$ MHz; HORIZONTAL POLARIZATION

Distance (cm)	Polarization					
	Horizontal			Vertical		
	w/o	w/	increase (%)	w/o	w/	increase (%)
0.5	0.82	0.82	0	1.03	1.12	8.7
4.0	0.39	0.41	6.0	0.45	0.48	6.7
7.0	0.26	0.30	13.5	0.28	0.30	7.1
10.0	0.16	0.18	12.9	0.18	0.21	17
15.0	0.10	0.12	18	0.11	0.136	24

Fig. 8 shows the maximum SAR in the human head when exposed to radiation from a monopole antenna ($f = 900$ MHz, $f = 1900$ MHz). Figs. 9 and 10 show the SAR distributions on a vertical cross section of the human head containing the monopole antenna. These results show clear differences for the cases with and without the body effect, particularly for a separation distance of 4.0 cm between the antenna and head.

B. Monopole Antenna, Horizontal Polarization

The effect of the human body on the absorption by the head when antennas was also calculated for the case of horizontally polarized antenna. Only one frequency (i.e., 1900 MHz) was considered in this case. The results are shown in Table VI and Fig. 11. Results for the vertical polarization case are also listed for comparison.

From the results shown in Table VI, as well as those shown in Fig. 11, it is clear that the human body has much reduced effect in the horizontal polarization case. Highest difference between the cases with and without the human body was 13.5% compared to 53% for the vertical polarization case.

C. PIFA Antenna, Horizontal and Vertical Polarization

Finally, SAR values in human head when PIFA antenna was used were calculated with and without taking into account the

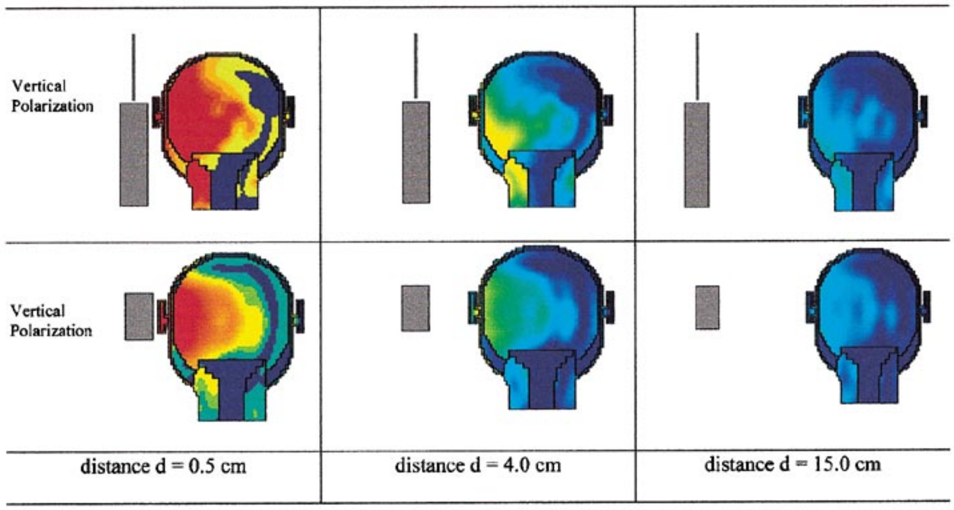


Fig. 11. Vertical cross sections of the human head showing SAR distributions for the vertical and horizontal polarization cases of monopole antenna at 900 MHz with and without body.

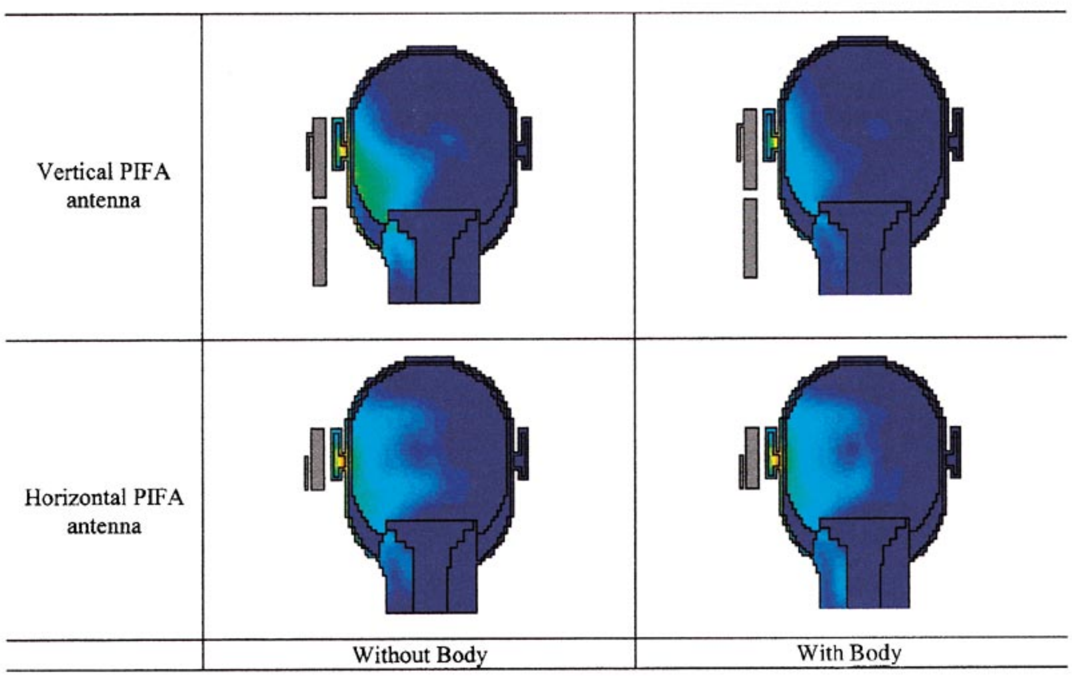


Fig. 12. Vertical cross sections of the human head showing SAR distributions for vertically and horizontally oriented PIFA antenna at 900 MHz with and without the effect of the human body.

TABLE VII
SARs in the Human Head: $f = 900$ MHz; PIFA Antenna

Distance (cm)	Polarization					
	Horizontal			Vertical		
	w/o	w/	increase (%)	w/o	w/	increase (%)
0.5	0.018	0.019	6	0.017	0.010	-41.0

effect of the human body. The results are presented in Table VII and Fig. 12 for 900 MHz and when the handset is vertically and horizontally placed.

From these results, the following observations may be made: 1) SAR values for the PIFA case are much smaller than those for the monopole case. 2) Both the vertical and horizontal orientations of the PIFA antenna show similar SAR distribution, and differences between the cases with and without the human body are just differences between small SAR values.

V. Conclusion

The multigrid FDTD code was used to evaluate the SAR values and distributions in the human head taking into account the effect of the human body. Two antenna geometries were used in the calculations, i.e., monopole with a metal box and the PIFA antennas, at two frequencies, i.e., 900 and 1900 MHz. Furthermore, calculations were made to examine the effect of the antenna orientation on the calculated SAR values. From the obtained results for vertically oriented monopole antenna at 900 MHz, it is shown that neglecting the effect of the human body may result in underestimating SAR values by 53% when the separation distance between the head and the handheld devices is 4 cm. An isolated model of the human head with a neck, on the other hand, provide reasonably accurate SAR results when the handheld device is held very close to the head (e.g., $\text{distance} = 0.5$ cm). Less dramatic differences between the calculations with and without the human head were observed at the higher frequency of 1900 MHz. SAR results for the PIFA antenna were much lower than those for the monopole antenna, and while for the vertical orientation case the human body resulted in a small change in SAR, the results from the horizontal orientation of the antenna were smaller when human body effects were taken into account.

For the case that demonstrated the most significant effect on the SAR in the human head, $f = 900$ MHz, a monopole antenna placed at a distance of 4 cm from the head, the radiation pattern of the antenna was also calculated and presented.

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