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A Comparative Study of the SAR Reduction Techniques for the Effects of Electromagnetic Waves on Human Head

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: In this paper, a comparison between three different human head models with three different types of antennas is presented to show the effect of shielding technique on the reduction of SAR. The three human head models presented are SAM phantom, six-layer, and two-tissue models. The three different types of antennas that are studied in this research are monopole, dipole, and helix antenna. Studying the parameters that affect the SAR value such as ferrite shield dimensions and position are also taken into consideration in this study to end up with a recommendation for the best model that achieves the optimum SAR reduction value.
Place of Study: Department of Electronics and Communication Engineering, Faculty of Engineering, University of Zagazig.
Results: The results have been obtained using CST Microwave Studio for the 3D EM simulation of high frequency components.

Keywords: Electromagnetic waves; ferrite shield; human head model; SAR distribution; SRF.

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1. INTRODUCTION

Human body is exposed continuously to the electromagnetic waves from cell phones, wireless routers and other radio frequency (RF) transceivers. Electromagnetic radiation absorbed by human tissue leads to health hazard such as brain tumors, childhood leukemia, miscarriage, cardiovascular effects, Alzheimer disease, genotoxic effects, breast cancer, DNA damage and micro nucleation [1-3]. There are different techniques to reduce the effect of electromagnetic waves on human body by shielding with microwave absorbing material such as ferrite material [1,4-7] or metamaterial [8-10] or resistive card (R-card) [11]. This research concerned with shielding with ferrite material. Attaching a ferrite shield to cell phone between human head and antenna reduces the amount of electromagnetic radiation power absorbed by human tissue to specific absorption rate. Specific Absorption Rate (SAR) is defined as [3,7,11,12]:

$$SAR = \sigma E^2 / (2\rho) \qquad \text{(W/Kg)} \tag{1}$$

Where σ is the conductivity of the human tissue (S/m), E is the induced electric field intensity (V/m) and ρ is the mass density of the human tissue (Kg/m^3). SAR values averaged over 1 g and 10 g of human tissue were denoted as SAR_{1g} and SAR_{10g} respectively. IEEE C 95.1: 1999 specify the SAR limit as 1.6W/Kg averaged over 1 g of human tissue while IEEE C 95.1: 2005 specify the SAR limit to be 2 W/Kg averaged over 10 g of human tissue [13]. SAR value must not exceed the threshold levels to avoid bad effects on human health. SAR Reduction Factor (SRF) is defined as [4]:

$$SRF_{1g}\,(\%) = \frac{SAR\ 1g - SAR1g,s}{SAR1g} \times 100 \tag{2}$$

$$SRF_{10g}\,(\%) = \frac{SAR\ 10g - SAR10g,s}{SAR10g} \times 100 \tag{3}$$

Where SRF_{1g} is SAR reduction factor for 1 g peak SAR, SRF_{10g} is SAR reduction factor for 10 g peak SAR, SAR_{1g} is 1 g peak SAR without shielding, SAR_{10g} is 10 g peak SAR without shielding, $SAR_{1g,s}$ is 1 g peak SAR with shielding and $SAR_{10g,s}$ is 10 g peak SAR with shielding.

The Table 1 gives an idea about some important work that done before for SAR reduction using different reduction technique.

2. MATERIALS AND MODELING

2.1 Ferrite Shield

Shielding is performed by ferrite material shield which has relative permittivity (ε_r) of 7–j0.6, relative permeability (μ_r) of 2.8–j3.3, electrical conductivity (σ_1) of 0.030042 S/m, magnetic conductivity (σ_2) of 23450.18 Ω.m-1 and mass density (ρ) of 5270 Kg/m3 [4]. Shield size is 80 mm height, 40 mm width and 3 mm thickness.

2.2 Human Head Model

Human head is modeled by different models such as SAM phantom model, six-layer model and two-tissue human head model. SAM phantom human head model is provided by CST Microwave Studio [14]. Six-layer human head model consists of six tissues skin, fat, bone, dura, cerebrospinal fluid (CSF) and brain [12]. Two-tissue human head model consists of two tissues bone and brain [4]. The properties of the six-layer human head model and the two-tissue human head model at 900MHz are shown in Table 2.

2.3 Antenna Model

The different parameters of the three different antenna models that have been used in this study are introduced in this section. Cell phone with monopole antenna is modeled by perfect electric conductor (PEC). Cell phone size is 100 mm length, 40 mm width and 20 mm thickness. Monopole antenna is λ / 4 length, 2.5 mm feeding gap and 0.45 mm radius [4]. Cell phone with helix antenna is provided by CST MWS [14]. Dipole antenna is 149 mm length, 0.745 mm feeding gap and 1.8 mm radius [12].

Table 1. Comparison of peak SAR

Ref.	SAR_{1g} (W/Kg) without shielding	SAR_{10g} (W/Kg) without shielding	SAR_{1g} (W/Kg) with shielding	SAR_{10g} (W/Kg) with shielding	Shielding technique
[5]	2.002	1.293	1.043	0.676	Ferrites
[6]	2.002	1.293	1.043	0.676	Ferrites
[6]	2.002	1.293	1.1607	0.737	Metamaterials
[7]	2.002	1.293	1.043	0.676	Ferrites

Table 2. Human head tissue properties

Human head model	Tissue	Relative permittivity (εr)	Conductivity σ (S/m)	Mass density ρ (Kg/m3)	Radius (mm)
Six-layer model	Skin	40.7	0.65	1100	83.25
	Fat	10	0.17	920	82.25
	Bone	20.9	0.33	1850	82.11
	Dura	40.7	0.65	1050	81.7
	CSF	79.1	2.14	1060	81.2
	Brain	41.1	0.86	1030	81
Two-tissue model	Bone	8	0.105	1850	100
	Brain	55	1.23	1030	90

3. DESCRIPTION OF THE SIMULATION ENVIRONMENT

The simulations are performed with CST Microwave Studio (CST MWS) software using finite-difference time-domain (FDTD) method. Mesh type is hexahedral and solver type is transient solver. The output power of the antenna is 500 mW at the operating frequency of 0.9 GHz. Practically the output power of the cell phone does not exceed 250 mW for normal use, while the maximum output power can reach till 1W or 2W when the base station is far away from the cell phone [8]. Spacing between human head model and antenna is 20 mm in the case of helix and monopole antenna and 25 mm in the case of the dipole antenna.

4. RESULTS AND SIMULATIONS

4.1 SAM Phantom Human Head Model

4.1.1 SAM phantom human head model with monopole antenna

Human head is modeled by SAM phantom model with monopole antenna. Spacing between SAM phantom human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 1.401 W/Kg for SAR_{1g} and 0.7389 W/kg for SAR_{10g}. The Ferrite shield is attached to the cell phone between SAM phantom human head model and monopole antenna as shown in Fig. 1. With ferrite shield attachment, the SAR values reduced to be 0.7303 W/Kg for SAR_{1g} and 0.4347 W/Kg for SAR_{10g} as shown in Fig. 2, respectively. SAR reduction factor of 47.87% for 1 g peak SAR and 41.17% for 10 g peak SAR are achieved.

Sweeping the SAR value over the different dimension of the shield (height, width, thickness and position) gives the results described in Figs. 3a-3d. Firstly; the SAR value is swept over the height of the ferrite shield between 20-100 mm whereas width equals 40 mm and thickness equals 3 mm. Secondly; the SAR value is swept over the width of the ferrite shield between 10-50 mm whereas height equals 80 mm and thickness equals 3 mm. Thirdly; the SAR value is swept over the thickness of the ferrite shield between 1-6 mm whereas height equals 80 mm and width equals 40 mm. Finally; the SAR value is swept over the position whereas height equals 80 mm, width equals 40 mm and thickness equals 3 mm.

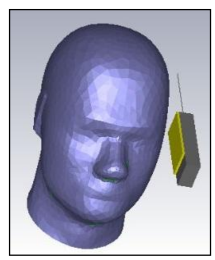

Fig. 1. Complete model used for simulation including SAM phantom model, cell phone, monopole antenna and ferrite shield

The results show that the SAR value decreases as the height, width or thickness of the ferrite shield is increased but the SAR value increases as the ferrite shield moves away from the monopole antenna.

4.1.2 SAM phantom human head model with helix antenna

In this section, human head is modeled by SAM phantom model with helix antenna. Spacing between SAM phantom human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 1.465 W/Kg for SAR_{1g} and 1.066 W/kg for SAR_{10g}. The Ferrite shield is attached to the cell phone between SAM phantom human head model and helix antenna.

With ferrite attachment, the SAR values reduced to be 0.8872 W/Kg for SAR_{1g} and 0.6421 W/Kg for SAR_{10g} as shown in Fig. 4, respectively The SAR reduction factor of 39.44% for 1 g peak SAR and 39.76% for 10g peak SAR are achieved.

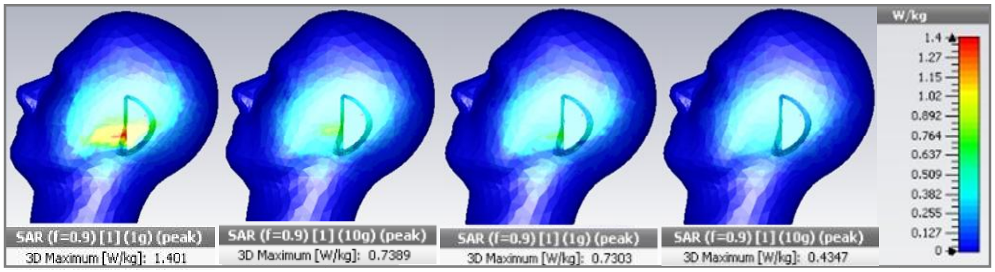

Fig. 2. SAR distribution over SAM phantom human head model with monopole antenna

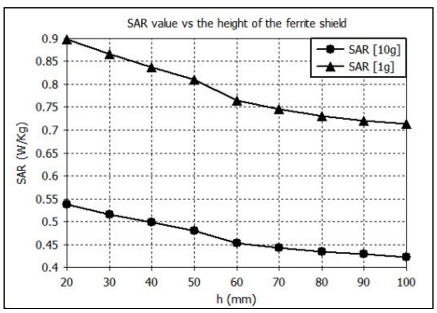

Fig. 3a. SAR value versus ferrite shield height

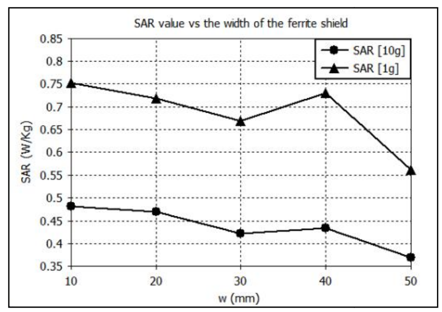

Fig. 3b. SAR value versus ferrite shield width

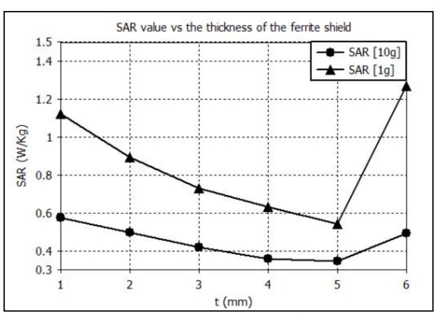

Fig. 3c. SAR value versus ferrite shield thickness

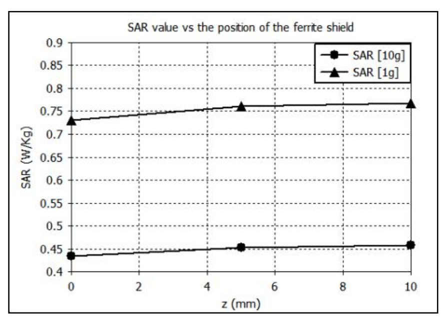

Fig. 3d. SAR value versus shield position along positive z-axis

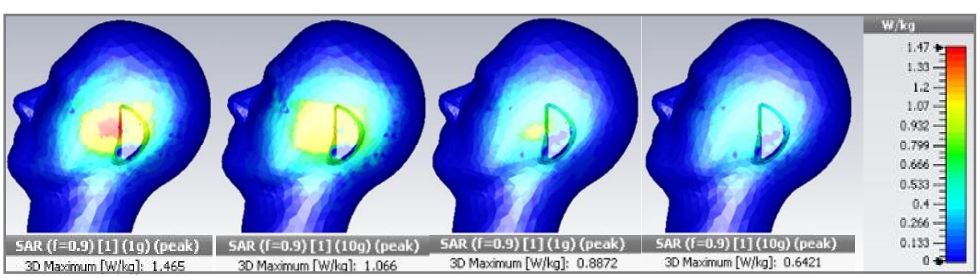

Fig. 4. SAR distribution over SAM phantom human head model with helix antenna

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 5a-5d.

4.1.3 SAM phantom human head with dipole antenna

Human head is modeled by SAM phantom model with dipole antenna. Spacing between SAM phantom human head model and the feeding point of dipole antenna is 25 mm. Without ferrite shield attachment, the SAR values are 2.985 W/Kg for SAR_{1g} and 1.506 W/kg for SAR_{10g}. The ferrite shield is attached between SAM phantom human head model and dipole antenna. With ferrite shield attachment, the SAR values reduced to be 0.8629 W/Kg for SAR_{1g} and 0.5807 W/Kg for SAR_{10g} as shown in Fig. 6, respectively. SAR reduction factor of 71.09% for 1 g peak SAR and 61.44% for 10g peak SAR are achieved.

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 7a-7d.

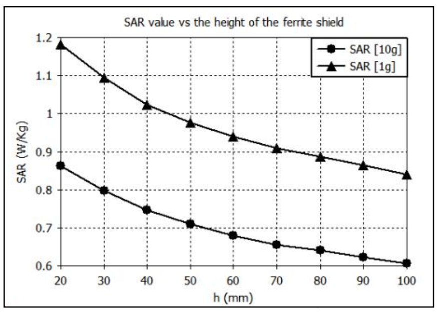

Fig. 5a. SAR value versus ferrite shield height

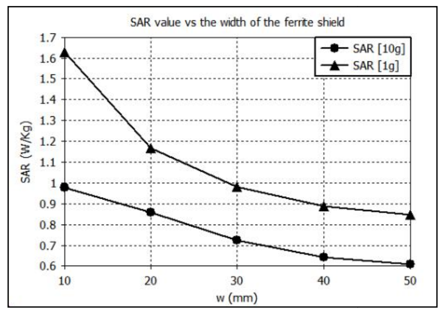

Fig. 5b. SAR value versus ferrite shield width

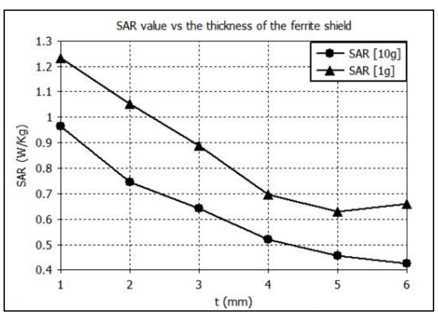

Fig. 5c. SAR value versus ferrite shield thickness

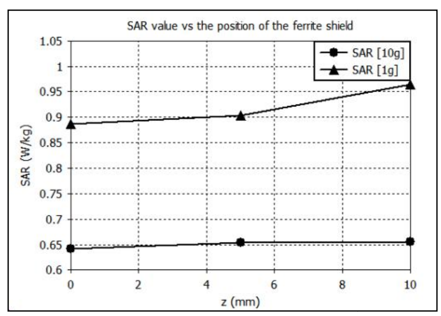

Fig. 5d. SAR value versus shield position along positive z-axis

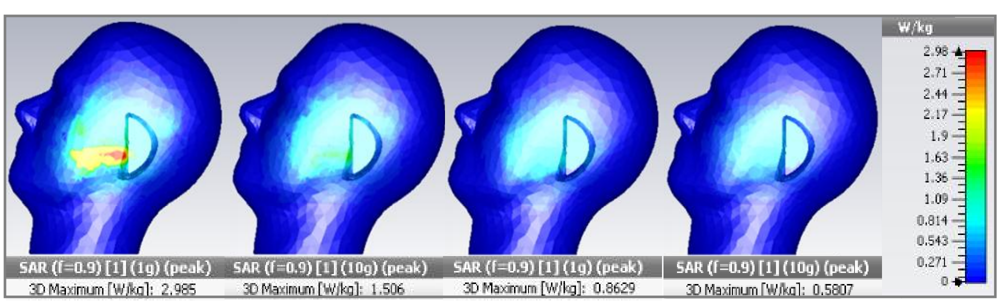

Fig. 6. SAR distribution over SAM phantom human head model with dipole antenna

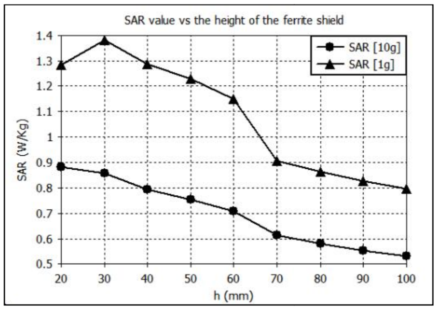

Fig. 7a. SAR value versus ferrite shield height

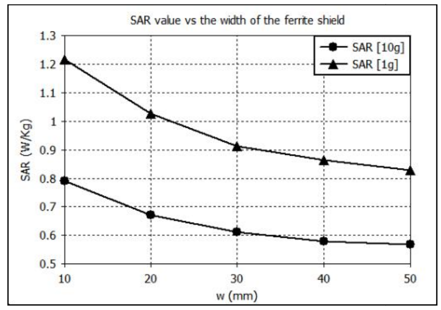

Fig. 7b. SAR value versus ferrite shield width

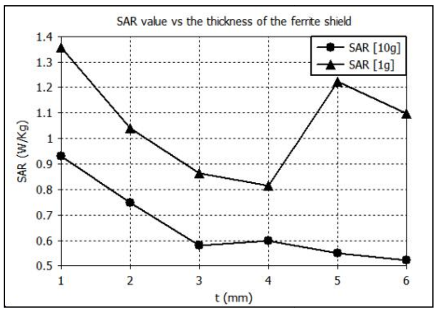

Fig. 7c. SAR value versus ferrite shield thickness

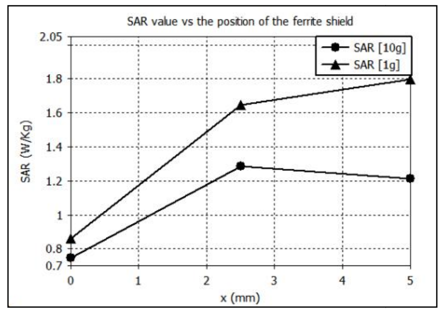

Fig. 7d. SAR value versus shield position along negative x-axis

4.2 Six-layer Human Head Model

4.2.1 Six-layer human head model with monopole antenna

Human head is modeled by six-layer model with monopole antenna. Spacing between six-layer human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 0.6899 W/Kg for SAR_{1g} and 0.5499 W/kg for SAR_{10g}. The ferrite shield is attached to the cell phone between six-layer human head model and monopole antenna as shown in Fig. 8. With ferrite shield attachment, the SAR values reduced to be 0.4918 W/Kg for SAR_{1g} and 0.4239 W/Kg for SAR_{10g} as shown in Fig. 9, respectively. SAR reduction factor of 28.71% for 1 g peak SAR and 22.91% for 10 g peak SAR are achieved.

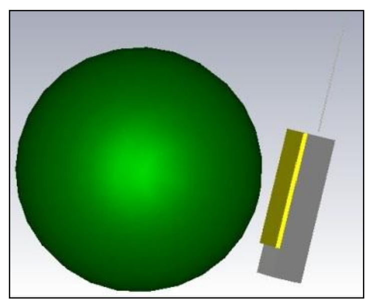

Fig. 8. Complete model used for simulation including six-layer model, cell phone, monopole antenna and ferrite shield

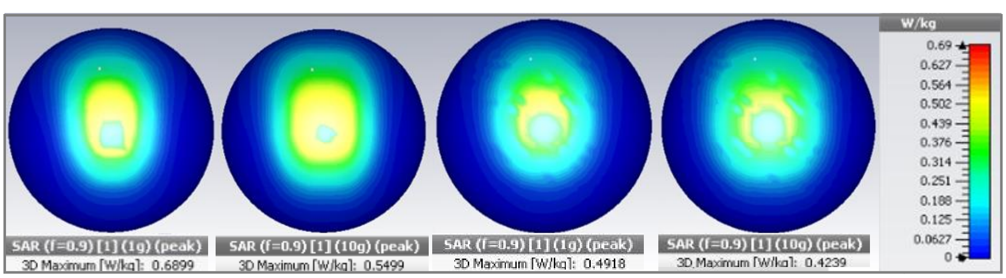

Fig. 9. SAR distribution over six-layer human head model with monopole antenna

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 10a-10d.

4.2.2 Six-layer human head model with helix antenna

Human head is modeled by six-layer model with helix antenna. Spacing between six-layer human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 2.313 W/Kg for SAR_{1g} and 1.699 W/kg for SAR_{10g}. The ferrite shield is attached to the cell phone between six-layer human head model and helix antenna. With ferrite shield attachment, the SAR values reduced to be 1.517 W/Kg for SAR_{1g} and 1.119 W/Kg for SAR_{10g} as shown in Fig. 11, respectively. SAR reduction factor of 34.41% for 1 g peak SAR and 34.13% for 10 g peak SAR are achieved.

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 12a-12d.

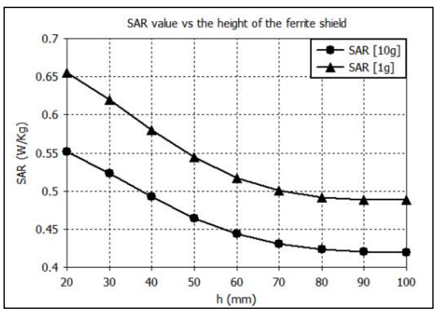

Fig. 10a. SAR value versus ferrite shield height

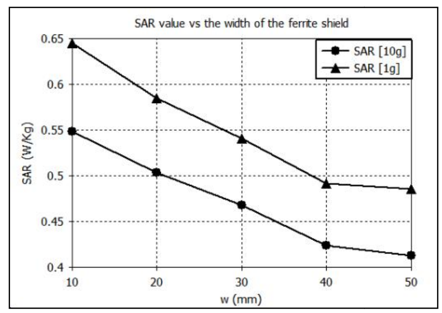

Fig. 10b. SAR value versus ferrite shield width

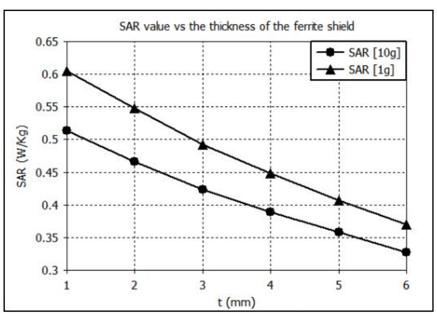

Fig. 10c. SAR value versus ferrite shield thickness

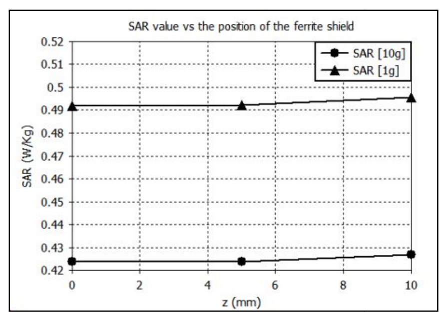

Fig. 10d. SAR value versus shield position along positive z-axis

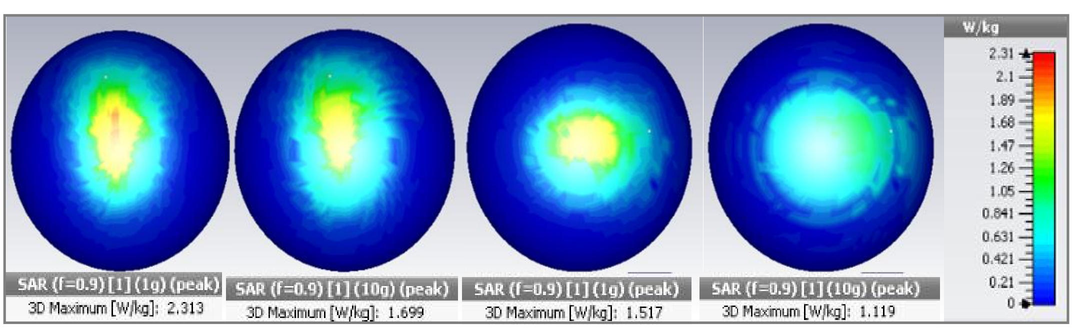

Fig. 11. SAR distribution over six-layer human head model with helix antenna

4.2.3 Six-layer human head model with dipole antenna

Human head is modeled by six-layer model with dipole antenna. Spacing between six-layer human head model and the feeding point of dipole antenna is 25 mm. Without ferrite shield attachment, the SAR values are 1.642 W/Kg for SAR_{1g} and 1.279 W/kg for SAR_{10g}. The ferrite shield is attached between six-layer human head model and dipole antenna. With ferrite shield attachment, the SAR values reduced to be 0.9483 W/Kg for SAR_{1g} and 0.7587 W/Kg for SAR_{10g} as shown in Fig. 13, respectively. SAR reduction factor of 42.24% for 1 g peak SAR and 40.68% for 10 g peak SAR are achieved.

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 14a-14d.

4.3 Two-tissue Human Head Model

4.3.1 Two-tissue human head model with monopole antenna

Human head is modeled by two-tissue model with monopole antenna. Spacing between two-tissue human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 0.7462 W/Kg for SAR_{1g} and 0.5622 W/kg for SAR_{10g}. The ferrite shield is attached to the cell phone between two-tissue human head model and monopole antenna. With ferrite shield attachment, the SAR values reduced to be 0.61 W/Kg for SAR_{1g} and 0.4615 W/Kg for SAR_{10g} as shown in Fig. 15, respectively. SAR reduction factor of 18.25% for 1 g peak SAR and 17.91% for 10 g peak SAR are achieved.

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 16a-16d.

4.3.2 Two-tissue human head model with helix antenna

Human head is modeled by two-tissue model with helix antenna. Spacing between two-tissue human head model and the cell phone is 20 mm. Without ferrite shield attachment, the SAR values are 1.42 W/Kg for SAR_{1g} and 1.076 W/kg for SAR_{10g}. The ferrite shield is attached to the cell phone between two-tissue human head model and helix antenna. With ferrite shield attachment,

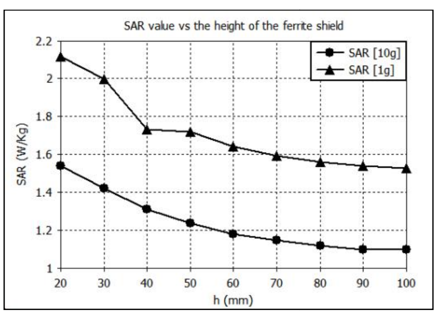

Fig. 12a. SAR value versus ferrite shield height

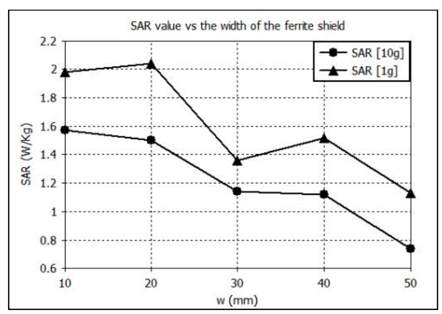

Fig. 12b. SAR value versus ferrite shield width

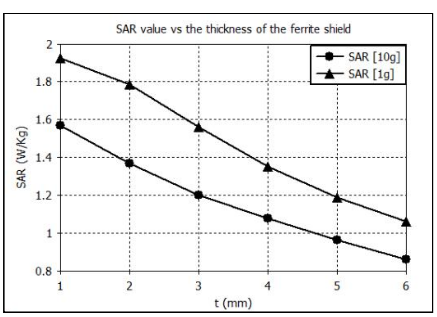

Fig. 12c. SAR value versus ferrite shield thickness

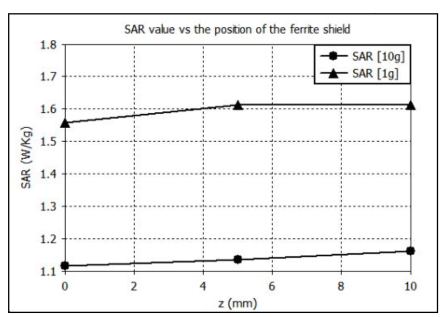

Fig. 12d. SAR value versus shield position along positive z-axis

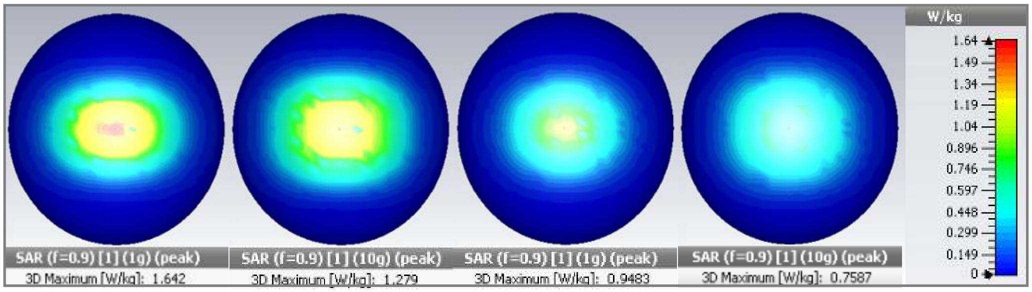

Fig. 13. SAR distribution over six-layer human head model with dipole antenna

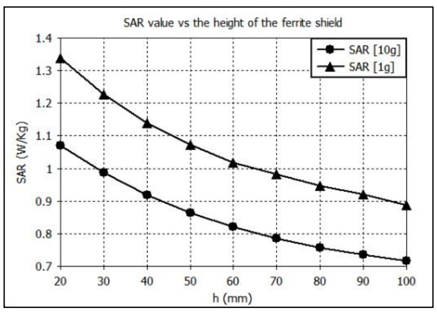

Fig. 14a. SAR value versus ferrite shield height

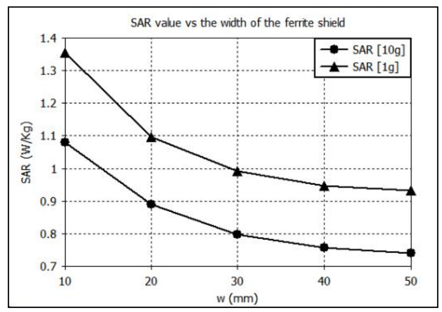

Fig. 14b. SAR value versus ferrite shield width

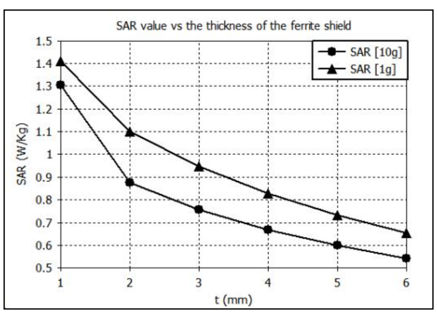

Fig. 14c. SAR value versus ferrite shield thickness

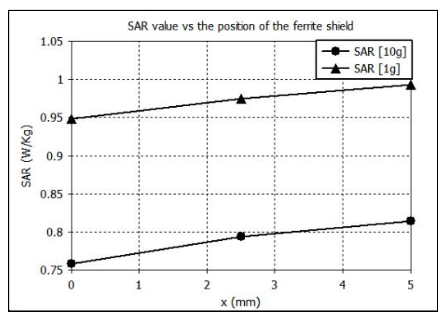

Fig. 14d. SAR value versus shield position along negative x-axis

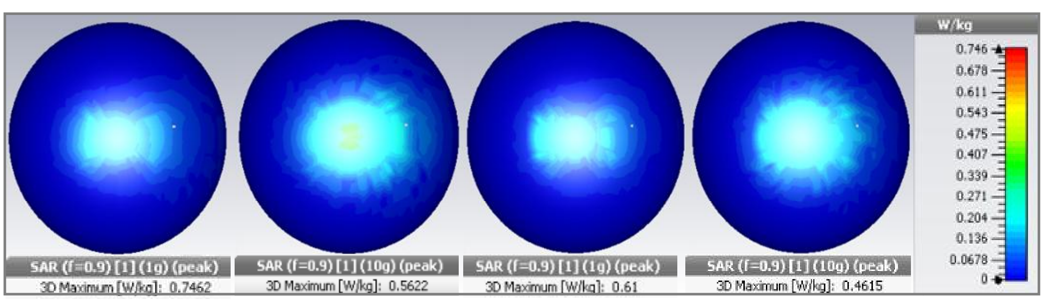

Fig. 15. SAR distribution over two-tissue human head model with monopole antenna

the SAR values reduced to be 0.894 W/Kg for SAR_{1g} and 0.6879 W/Kg for SAR_{10g} as shown in Fig. 17, respectively. SAR reduction factor of 37.04% for 1g peak SAR and 36.06% for 10g peak SAR are achieved.

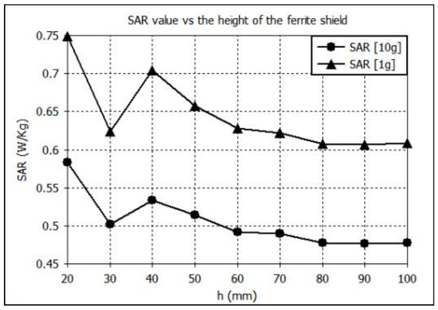

Fig. 16a. SAR value versus ferrite shield height

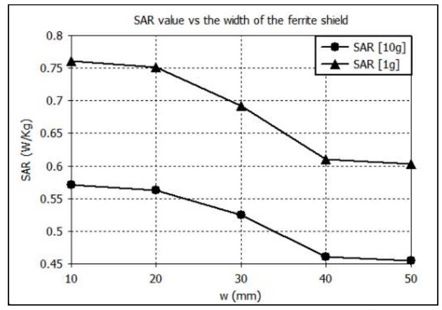

Fig. 16b. SAR value versus ferrite shield width

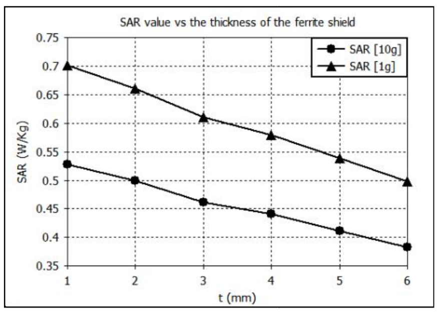

Fig. 16c. SAR value versus ferrite shield thickness

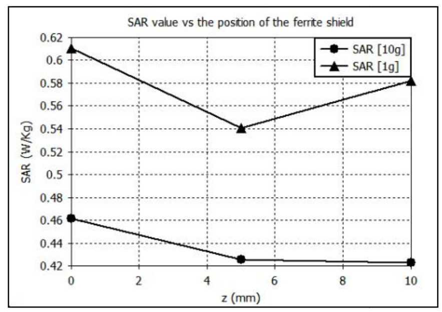

Fig. 16d. SAR value versus shield position along positive z-axis

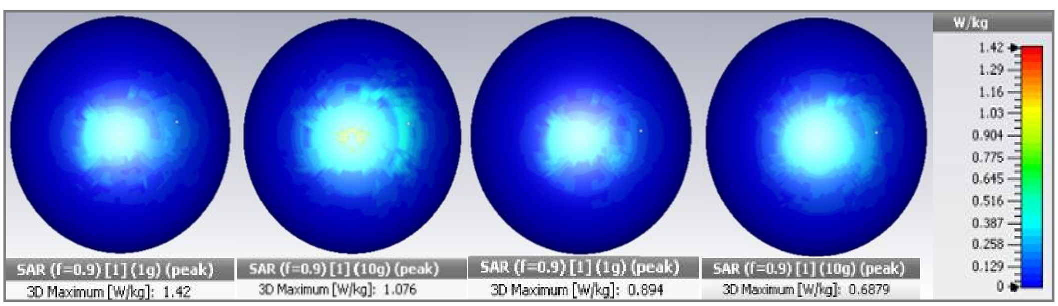

Fig. 17. SAR distribution over two-tissue human head model with helix antenna

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 18a-18d.

4.3.3 Two-tissue human head model with dipole antenna

Human head is modeled by two-tissue model with dipole antenna. Spacing between two-tissue human head model and the feeding point of dipole antenna is 25 mm. Without ferrite shield attachment, the SAR values are 1.544 W/Kg for SAR_{1g} and 1.1 W/kg for SAR_{10g}. The ferrite shield is attached between two-tissue human head model and dipole antenna. With ferrite shield attachment, the SAR values reduced to be 0.9798 W/Kg for SAR_{1g} and 0.696 W/kg for SAR_{10g} as shown in Fig. 19, respectively. SAR reduction factor of 36.54% for 1 g peak SAR and 36.72% for 10 g peak SAR are achieved.

The SAR values are swept over the different dimensions of the shield (height, width, thickness and position) as described before in section 4.1.1 and the obtained results are shown in Figs. 20a-20d.

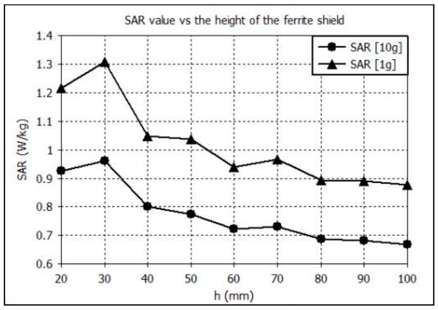

Fig. 18a. SAR value versus ferrite shield height

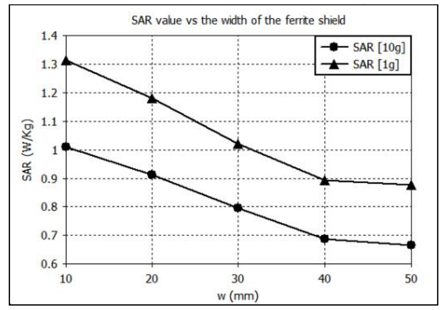

Fig. 18b. SAR value versus ferrite shield width

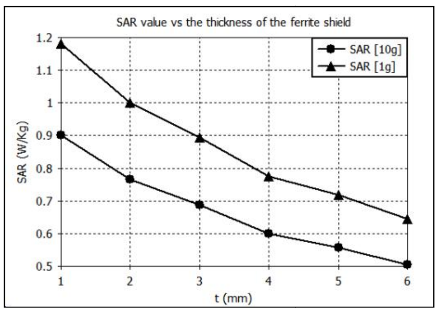

Fig. 18c. SAR value versus ferrite shield thickness

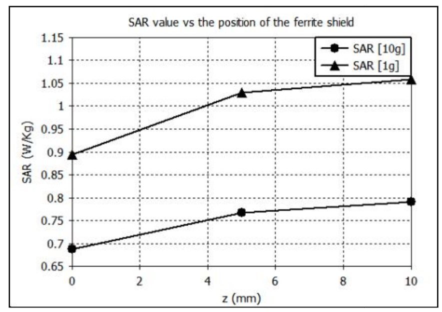

Fig. 18d. SAR value versus shield position along positive z-axis

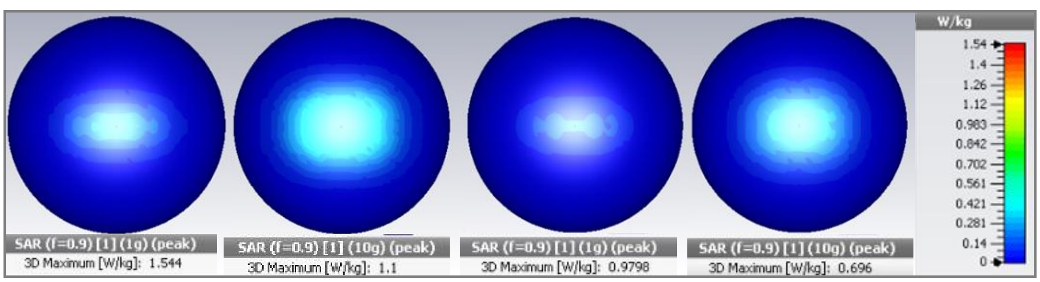

Fig. 19. SAR distribution over two-tissue human head model with dipole antenna

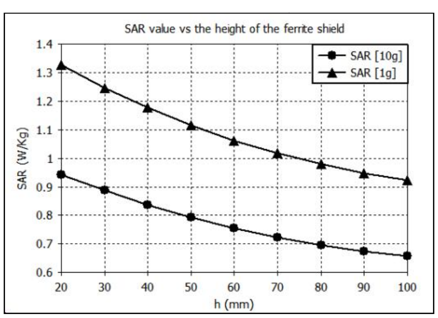

Fig. 20a. SAR value versus ferrite shield height

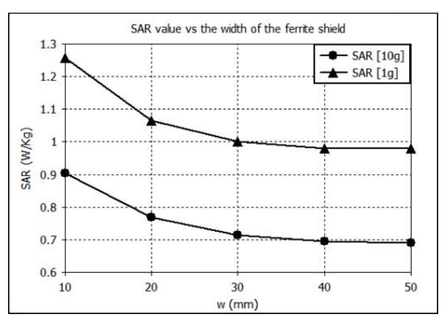

Fig. 20b. SAR value versus ferrite shield width

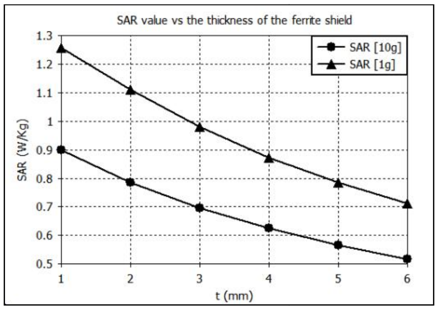

Fig. 20c. SAR value versus ferrite shield thickness

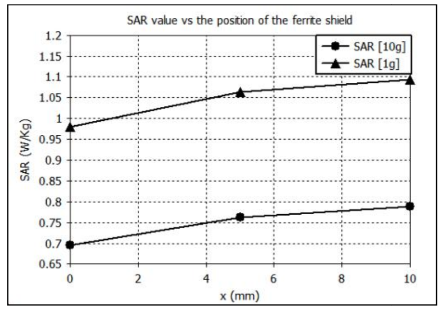

Fig. 20d. SAR value versus shield position along negative x-axis

Table 3. Comparison between SAR values with different human head model and different types of antenna

Human head model	Antenna type	Without shielding		With ferrite shield			
		SAR_{1g} (W/kg)	SAR_{10g} (W/kg)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)	SRF_{1g} (%)	SRF_{10g} (%)
SAM phantom model	Monopole	1.401	0.7389	0.7303	0.4347	47.87	41.17
	Helix	1.465	1.066	0.8872	0.6421	39.44	39.76
	Dipole	2.985	1.506	0.8629	0.5807	71.09	61.44
Six-layer model	Monopole	0.6899	0.5499	0.4918	0.4239	28.71	22.91
	Helix	2.313	1.699	1.517	1.119	34.41	34.13
	Dipole	1.642	1.279	0.9483	0.7587	42.24	40.68
Two-tissue model	Monopole	0.7462	0.5622	0.61	0.4615	18.25	17.91
	Helix	1.42	1.076	0.894	0.6879	37.04	36.06
	Dipole	1.544	1.1	0.9798	0.696	36.54	36.72

5. CONCLUSION

Simulation with SAM phantom human head model achieves SAR reduction factor greater than other models. For monopole antenna, SRF equals 47.87% for 1 g peak SAR and 41.14% for 10g peak SAR. For helix antenna SRF equals 39.44% for 1 g peak SAR and 39.76% for 10 g peak SAR. Shielding dipole antenna with ferrite achieves the largest SAR reduction factor of 71.09% for 1 g peak SAR and 61.44% for 10 g peak SAR as shown in Table 3. The SAR value decreases as the size of the ferrite shield increases. The SAR value increases as the ferrite shield moves away from the antenna.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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