Specific Absorption Rate (SAR) Induced in Human Heads of Various Sizes When Using a Mobile Phone

Adel Z. El Dein   Alaeddin Amr

***Abstract* - This paper analyzes the specific absorption rate (SAR) induced in human head model of various sizes by a mobile phone at 900 and 1800 MHz. Specifically the study is considering in SAR between adults and children. Moreover, these differences are assessed for compliance with international safety guidelines. Also the effects of these head models on the most important terms for a mobile terminal antenna designer, namely: radiation efficiency, total efficiency and directivity, are investigated.**

***Index Terms*—Human Head, Mobile Phone, SAR.**

I. INTRODUCTION

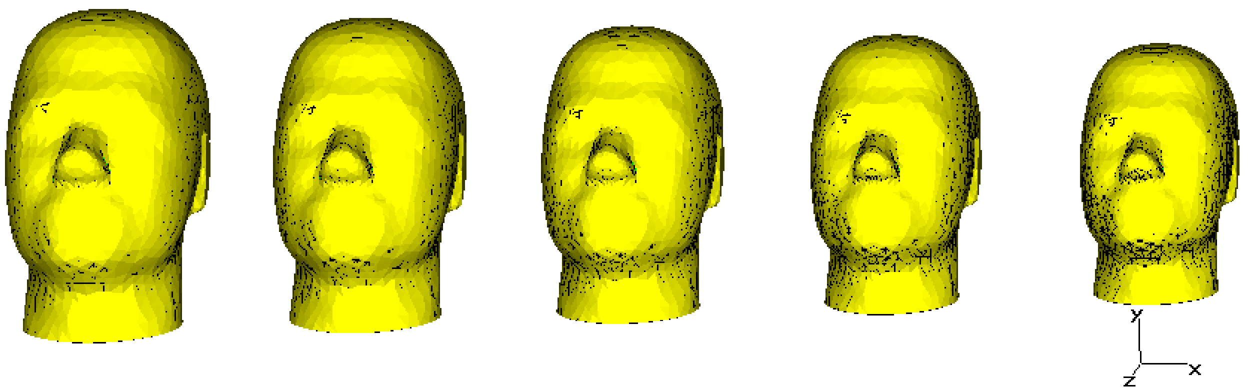
In recent years, much attention has been paid to health implication of electromagnetic (EM) waves, especially human head part, which is exposed to the EM fields radiated from handsets. With the recent explosive increase of the use of mobile communication handsets, especially the number of children using a mobile phone, that develops many questions about the nature and degree of absorption of EM waves by this category of public as a function of their age and their morphology. For this reason the World Health Organization (WHO) has recommended to undertake research studies on this subject [1]. This paper investigates the effects of head models of various sizes on the most important terms for a mobile terminal antenna designer, namely: radiation efficiency, total efficiency and directivity; and also on the Specific Absorption Rates (SAR) which are induced in them. For this purpose, a comparison is performed concerning those parameters between an adult human head and some children heads obtained as a percent of an adult human head. The results are obtained using an electromagnetic field solver employing the Integral Equations method [2]. The SAR is the most appropriate metric for determining EM effect exposure in the very near field of a Radio Frequency (RF) source [3-7]. The local SAR (W/kg) at any point in the human head is defined as:

$$SAR = \frac{\sigma E^2}{2\rho} \quad (1)$$

where E is the peak amplitude of the electrical field in the human head tissue (V/m), σ is the tissue conductivity (S/m) and ρ is the tissue density (kg/m^3). The SAR over a mass of 10g and 1g in the head and the other parameters of the mobile antenna are determined in each case.

II. MODELING OF HUMAN HEAD

For this study, five head models are used namely: that of an adult and other children human heads of sizes; 95%, 90%, 85%, and 80% of the adult head size (which of size 100%), as they are shown in fig. (1). Each head model consists of shell of skin tissue which is filled with a liquid of brain properties. For simulation of the EM fields in the human head, the appropriate parameters for the conductivity σ (S/m), the relative permittivity ε_r and the tissue density ρ (kg/m^3) of all different materials used for the calculation must be known. Additionally, the frequency dependence of these parameters must be considered and chosen appropriately. A recent compilation of Gabriel et al. covers a wide range of different body tissues and offers equations to determine the appropriate dielectric values at each desired frequency [8].



100%   95%   90%   85%   80%

Fig. 1 The description of the various sizes human head models

Table I shows the real part of the dielectric permittivity ε_r, conductivity σ (S/m), and mass density ρ (kg/m^3) of tissues used in the simulations at 900 and 1800MHz. Table II

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shows the volume and the mass of the tissue of all children heads.

Table I
THE DIELECTRIC PERMITTIVITY ε_r, CONDUCTIVITY σ (S/m), AND MASS DENSITY ρ (kg/m^3) OF TISSUES USED IN THE SIMULATIONS AT 900 AND 1800MHZ.

Properties of Tissues		Dielectric Permittivity ε_r	Conductivity σ (S/m)	Mass Density ρ(kg/m^3)
Shell (Skin)	900MHz	43.8	0.86	1000
	1800MHz	38.87	1.19	1000
Liquid (Brain)	900MHz	45.8	0.77	1030
	1800MHz	43.5	1.15	1030

Table II
VOLUME AND MASS OF THE HEADS' MODELS

The Volume and mass of the human Head	Human Head Size as a percent from an adult one.				
	100%	95%	90%	85%	80%
Tissue Volume (mm^3)*10^6	5.5893	4.7886	4.0706	3.4283	2.8573
Tissue Mass (kg)	5.7439	4.9236	4.1855	3.5250	2.9379

III. MODELING OF THE MOBILE PHONE

The mobile handset consists of a quarter-wavelength monopole (of radius 0.0025m at 900MHz and 0.001m at 1800MHz) mounted on a mobile handset (treated as a metal box of 1.8cm×4cm×10cm), operates at 900 and 1800MHz and radiated power of 0.125 watt, as it is shown in fig. 2.

Fig. 2 The description of the mobile handset

IV. RESULTS AND DISCUSSION

Figures (3) and (4) present mobile terminal antenna designer parameters namely: return loss, radiation efficiency, total efficiency and directivity, the results obtained with the absence of the human head and at a frequency 1800MHz. Table III present the Mobile Antenna Parameters, namely: radiation efficiency, total efficiency and directivity, the results obtained for various sizes of human heads and for the case of there absence. It is seen that as the size of human head decreases the radiation efficiency and total efficiency decrease, in the other side the directivity increases. The differences between the results of SAR of different kinds are given in Table IV, for each frequency and for each studied child head model.

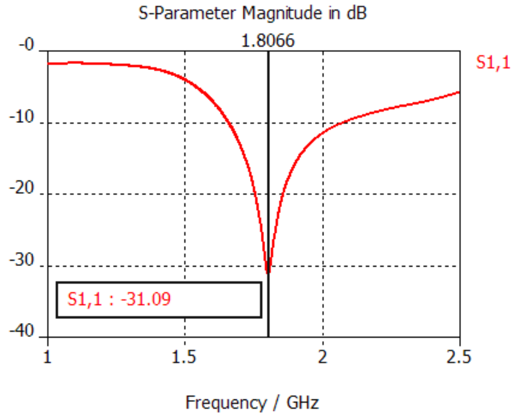

Fig. 3 The return loss without human head

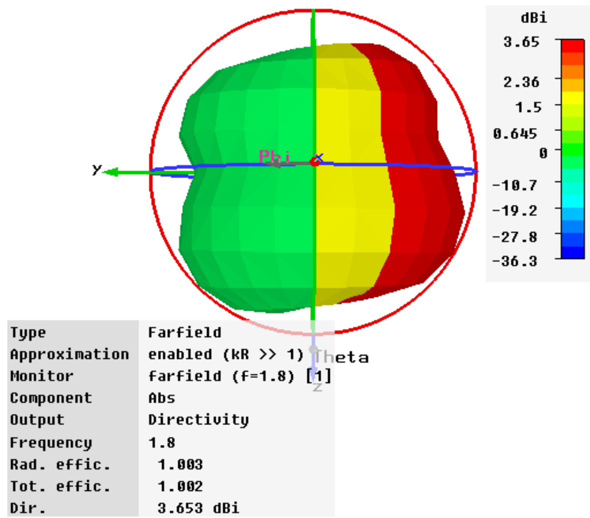

Fig. 4 The Far Field without human head

Table III
MOBILE ANTENNA PARAMETERS WITH VARIOUS SIZES OF HUMAN HEAD

Mobile Antenna Parameters		Without human Head	Human Head Size as a percent from an adult one.				
			100%	95%	90%	85%	80%
900 MHz	Rad. η	1.003	0.276	0.292	0.311	0.335	0.357
	Tot. η	0.788	0.271	0.286	0.305	0.328	0.35
	Dir. (dBi)	2.627	6.066	5.943	5.859	5.819	5.712
1800 MHz	Rad. η	1.003	0.485	0.498	0.512	0.528	0.546
	Tot. η	1.002	0.476	0.489	0.504	0.521	0.539
	Dir. (dBi)	3.653	7.98	7.855	7.756	7.673	7.552

The "SAR 10 grams" is the maximum SAR value averaged on 10g which is obtained by averaging the SAR around each point in the volume and adding the nearest points till an average mass of 10g is reached with a resulting volume having the shape of a portion of sphere. The "contiguous SAR 1 gram" is estimated by averaging the local maximum SAR, adding the highest SAR volume in a given tissue till a mass of 1g is reached. The SAR (point) is the local value of SAR at every point inside the head model. The results show that by decreasing the head size the peak SAR 1g and peak SAR 10g decrease, however the percentage of absorbed power in the human head increases. So, the local SAR (point) and total SAR in children's heads increase as children's heads decrease, as indicated in Table III. Also from Table III it is noticed that, the total SAR over the whole human head at 1800MHz is less than that at 900MHz. This is because the SAR regions produced by monopole antenna at 900 MHz are more extended as compared to those induced at 1800 MHz. The human body works as a barrier, mainly in high frequencies, because of skin depth. As the frequency increases the penetration capacity decreases and become more susceptible to obstacles.

Figures (5-10) show the distributions of the local SAR, at the y=0 plane; 10 grams SAR in xz plane; and 1gram SAR in xy plane; in (W/kg), on the human head of various sizes, obtained with a radiated power of 125mW from a monopole antenna operates at 900 and 1800MHz respectively. It can be easily noticed that high SAR regions produced by 900MHz monopole antenna are more extended as compared to those induced by 1800 MHz monopole antenna, as it is explained before.

Table IV
SAR INDUCED IN CHILDREN'S HEADS

Calculated Parameters of the human Head		Human Head Size as a percent from an adult one.				
		100%	95%	90%	85%	80%
900MHz	SAR (point)	1.134	1.206	1.124	1.122	1.214
	SAR 1g	0.818	0.805	0.785	0.769	0.769
	SAR 10g	0.593	0.59	0.584	0.58	0.572
	Absorbed Power (W_{rms})	0.089	0.087	0.085	0.082	0.079
	Total SAR (W/kg)	0.016	0.018	0.02	0.023	0.027
1800MHz	SAR (point)	4.149	3.078	2.404	2.319	2.282
	SAR 1g	1.590	1.530	1.482	1.399	1.312
	SAR 10g	0.922	0.887	0.848	0.805	0.764
	Absorbed Power (W_{rms})	0.064	0.062	0.060	0.058	0.056
	Total SAR (W/kg)	0.011	0.012	0.014	0.016	0.019

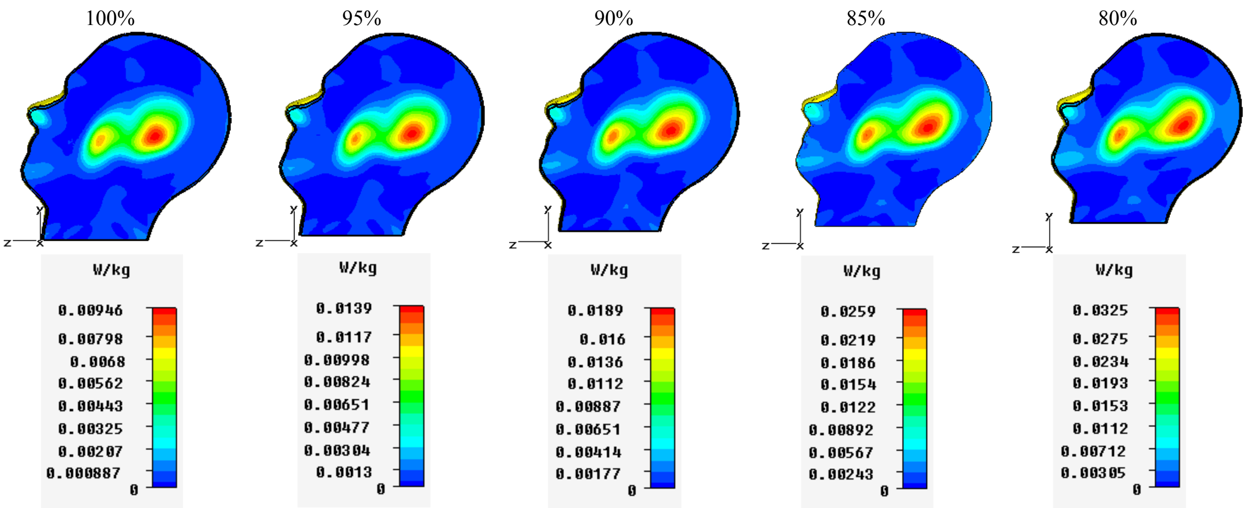

Fig. 5 The distributions of the local SAR at x=0 plane for 1800MHz

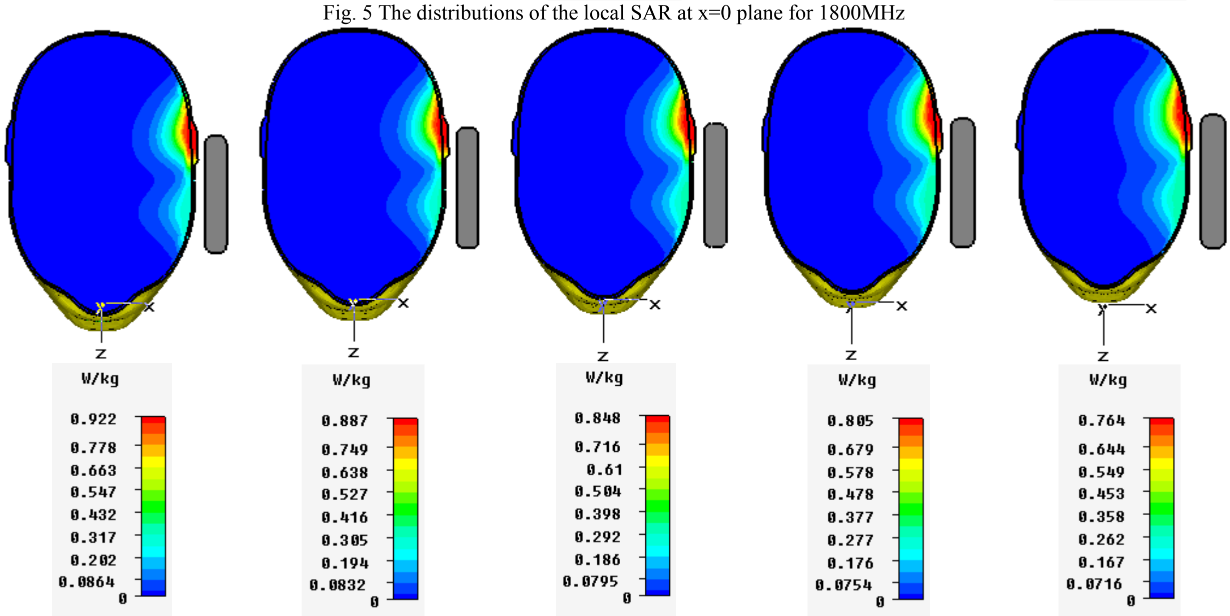

Fig. 6 The distributions of the (10g) SAR at xz plane for 1800MHz

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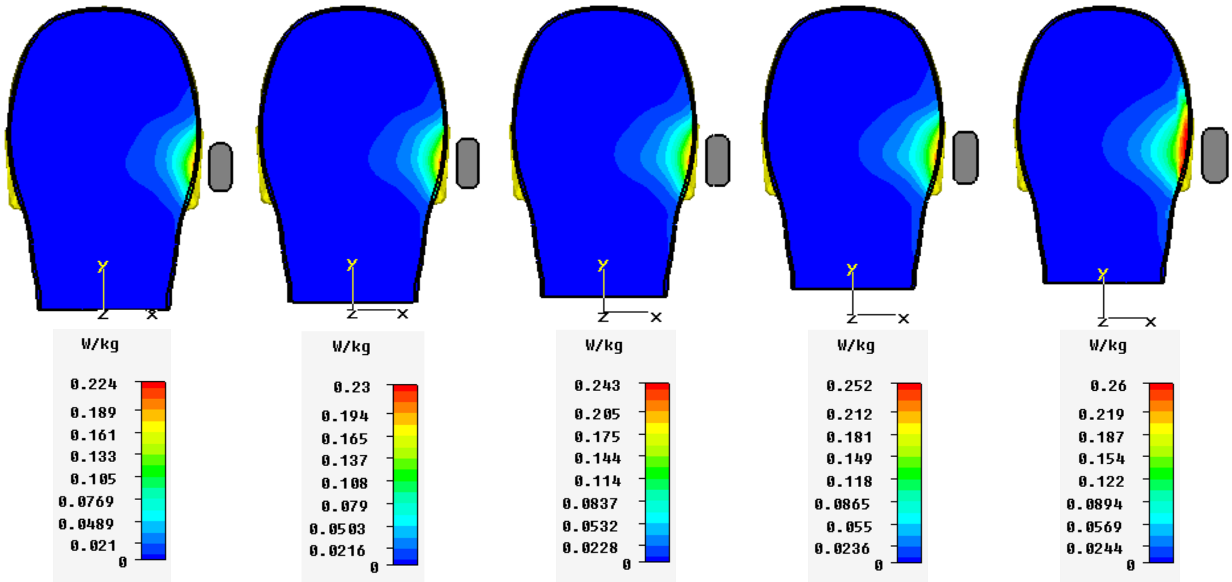

Fig. 7. The distributions of the (1g) SAR at xy plane for 1800MHz

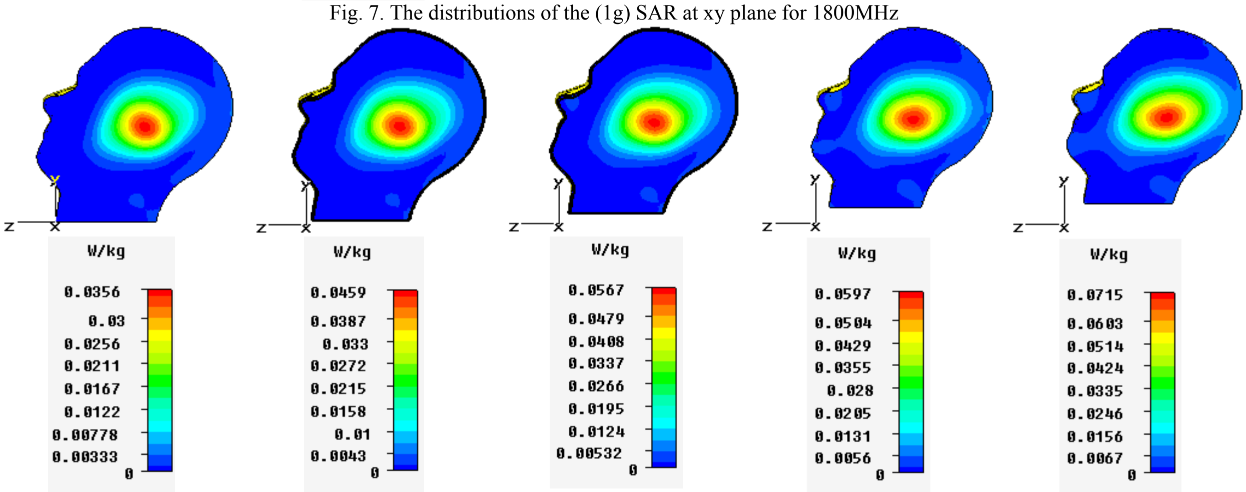

Fig. 8 The distributions of the local SAR at x=0 plane for 900MHz

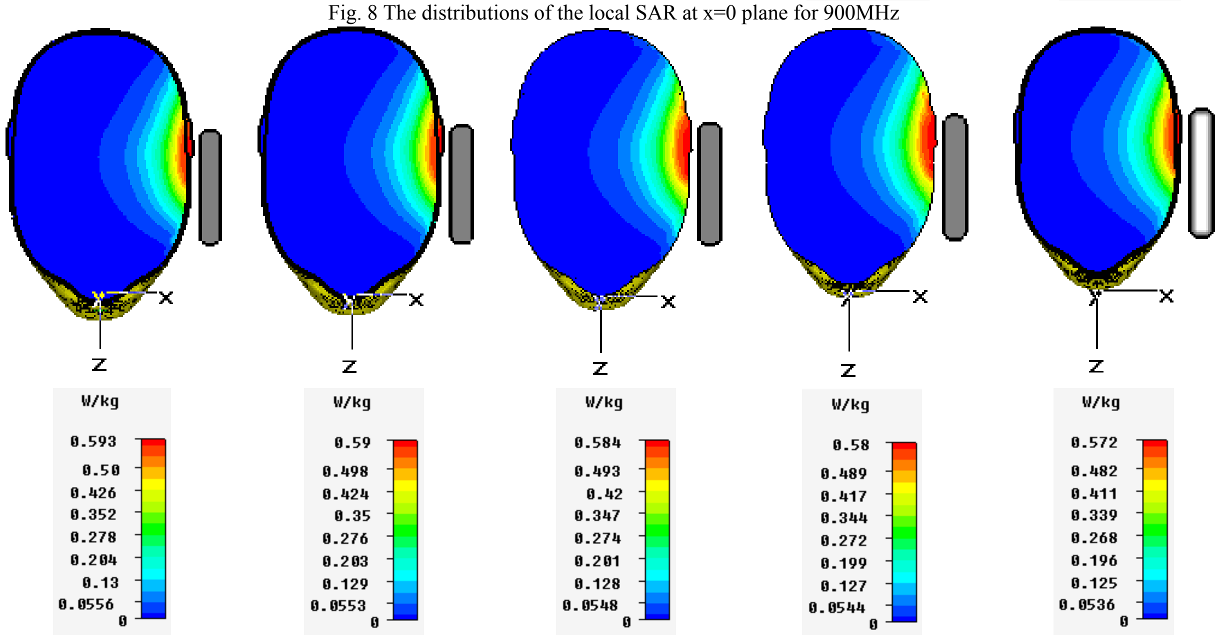

Fig. 9 The distributions of the (10g) SAR at xz plane for 900MHz

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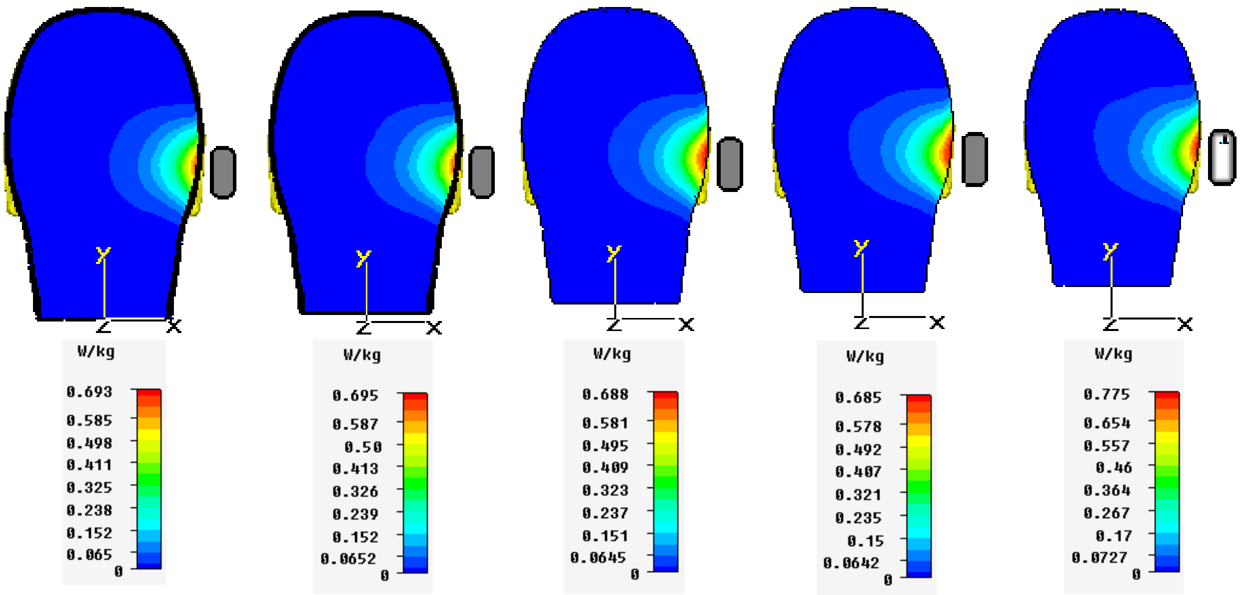

Fig. 10 The distributions of the (1g) SAR at xy plane for 900MHz

V. Conclusion

The obtained results show that the spatial-peak SAR values at a point or as averaged over 1 gram and 10 grams on the human head of various sizes, obtained with a radiated power of 125mW from a monopole antenna operates at 900 and 1800MHz, vary with the size of the human's head at each frequency. Also the sizes of the head have an effect on the mobile terminal antenna designer parameters, and this effect can't be eliminated, because it is an electromagnetic characteristic. The obtained results show that the spatial-peak SAR values as averaged over 1 gram on the human head obtained with a radiated power of 0.125 watt for all simulations are well below the limit of 1.6 W/kg, which is recommended by FCC and ICNIRP [9-11].

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