Comparative assessment of the mobile phones' EMF absorption between adults and children head models

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Abstract: - In this paper some aspects concerning the finite element modeling of the interaction between the EMF radiated by a half-wavelength dipole antenna and 2D finite element simulations of six human models have been carried out. The head geometries for an adult and for a child are considered. The SAR peak values and the absorbed power values are evaluated for different frequencies. The adult and children results are compared with those from 3D models in the literature.
Key-Words: - finite element method, magnetic frill, SAR

1 Introduction

A great growth of the numbers and diversity of electromagnetic field (EMF) sources used for individual, industrial, commercial and medical purposes have been observed in the last years. Radio and TV, microwave oven, mobile phones, computers, and RADAR systems are the most common .

There has been an increasing public concern about possible health hazards resulting from exposure to the electromagnetic field that PDCs(personal digital cellulars) radiate.

The problem of computing the electromagnetic field configuration induced by a cell phone in the human head should take into account certain elements [1] :

- The ratio between the head size and the emission frequency
- The geometry of the human head and the dielectric properties of the tissues (skin, bone, brain).
- The antenna geometry: loop, monopole, dipol, microstrip
- The mathematical method used to perform the modelling: finite difference time domain FDTD, finite element method, method of moments, finite volume method.

As a consequence researches have been oriented in the direction of finding reliable means of analyzing mobile phone for radiation pattern performance to address the safety concern. EMF produced by an antenna can be described as having several components [2]. Only one of these actually propagates through space. This component is called the radiated field or the far field. The strength of the radiated field decreases with distance, since the energy must spread as it travels. The other components of the electromagnetic field remain near the antenna and do not propagate. There are generally two other components: the static field and the induction field. Their strength decreases very rapidly with distance. The entire field – all of the components near the antenna is called the near field. In this region, about one wavelength in extent, the electric field can be relatively high and create a hazard to the human body. Biomedical research in this field is based on the analysis of the EMF interactions with body tissues and on epidemiological studies. The usefulness of numerical modeling as well as measurements of SAR and E inside the body has been demonstrated in the assessment of the biological effects and in setting the safety exposure guidelines and the certification protocol for harmless microwave devices used in medicine, transportation and communications systems.

The EMF analysis is performed by solving the electromagnetic wave equations in time harmonic regime (Helmholtz type PDEs).The solutions can be obtained either by analytical [3] or by numerical methods.

The most versatile are the Method of Moments, the finite-difference time domain method (FDTD) [4], [5], [6] and the finite element method [2], [7], [8],

[9].The fem is more suitable to complex and non homogenous media [8].In this paper emphasis is placed on the comparative study of EM waves energy absorption between adults and children 2D head models. Simulations based on finite element method were performed in order to estimate their efficiency.

2. Problem formulation

2.1 SAR (Specific absorption rate) of the electromagnetic radiation in biologic structure

Because the electromagnetic radiation interacts with the biological systems in a complex way it is difficult to evaluate and quantified the power absorption. The coupling and the transfer energy to the irradiated tissues varies in a large range. The fundamental parameters are the electric and magnetic field components induced by the incident radiation in a certain biological area. Related with these components are the induced currents in the tissues and their dissipated amount of energy and also the size and the shape of the considered domain. The incident electromagnetic field on a biological structure can be expressed as a power density (mW/cm^2) or as the amplitude of the electric field (V/m) or of the magnetic field (A/m).None of these parameters is suitable to express the effects induced by the penetration of the electromagnetic radiation in a biological structure. In this case, is defined a specific parameter named Specific Absorption Rate (SAR) as the time derivative of the infinitesimal energy dw absorbed by a an infinitesimal mass dm of an infinitesimal volume dv of a given mass density ρ [1]

$$SAR(W/Kg) = \frac{d}{dt}\left(\frac{dw}{dm}\right) = \frac{d}{dt}\left(\frac{dw}{\rho dv}\right) \qquad (1)$$

This parameter depends on many elements:

- the geometry and the dielectric properties of the irradiated media.
- the geometry, the localization and the orientation of the radiation source versus the biological structure
- the incident electromagnetic wave polarization
- focalization of the electromagnetic wave
- modulation of the electromagnetic incident field

The SAR parameter is computed with the expression:

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

where E is the rms value of the electric field strength in time harmonic regime. For RF near field exposures the safety standards are based on the local peak SAR averaged over 1 or 10 g of tissue.

The interaction of the time harmonic EMF and human body at microwave frequencies is usually described in terms of complex permittivity [11] $\underline{\varepsilon} = \varepsilon - j \cdot \frac{\sigma}{\omega}$ or of complex conductivity $\underline{\sigma} = \sigma + j\omega\varepsilon$, where ε the electric permittivity is, σ is the electric conductivity and $\omega = 2\pi f$ is the angular frequency of the EMF. The biological tissues in this frequency range are considered lossy conductive dielectric materials. Their relative magnetic permeability is considered to be equal with 1.

2.2 Theoretical aspects

Many 2D and 3D models used by different authors in order to estimate the SAR distribution in human head models exposed to the electromagnetic field radiated by a mobile phone are described in literature.

The time harmonic form of the electromagnetic waves equations for the electric and magnetic field respectively are of Helmholtz type:

$$\nabla \times \left(\frac{1}{\mu}\nabla \times \underline{\overline{E}}\right) - \omega^2 \underline{\varepsilon}\underline{\overline{E}} = 0$$
$$\nabla \times \left(\frac{1}{\mu}\nabla \times \underline{\overline{H}}\right) - \omega^2 \underline{\mu_0 H} = 0 \qquad (3)$$

The time harmonic form of the electromagnetic waves equations for the magnetic field is of Helmholtz type, and for the 2D model becomes [12]:

$$\left(\left(\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}\right)^{-1}\nabla \times H_z\right) - \mu_0 k_0^2 H_z = 0$$

where $\varepsilon_r = n^2$, where n is the refractive index.

The computations were performed using Comsol RF module finite element method, transversal magnetic (TM) waves application mode, time-harmonic sub mode.

The EMF source considered was a half wavelength dipole antenna fed at the center. Generally the dipole fed antenna models are voltage driven. In order to model a voltage generator the magnetic frill approach was used. This approach can be used only with the wave formulation using H field.

3. Problem solution

In order to asses differences in EM energy absorption for adults and children, certain head models with different sizes have been considered. From the dosimetry handbook [5] the height of a average adult is 176 cm and the weight 71 kg.

The height of an average 10 years old child is 138 cm and the weight 32.5 kg respectively.
Therefore the dimensions for the children head models have been obtained from the adults by a scaling factor of $\left(\left(\frac{176}{138}\right)\left(\frac{32.5}{71}\right)\right)^{1/2}$.

The finite element method was used to study exposure of the head models at 900 MHz, 1710 MHz and 1800 MHz respectively.

3.1 2D homogenous and three layer spherical models exposed to 1710 MHz.

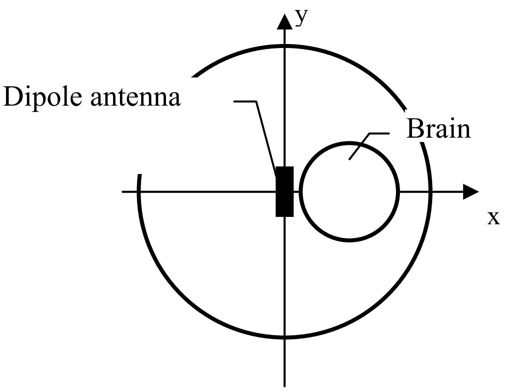


Fig.1Homogenous head model

The homogenous model is presented in Fig.1, being a sphere of brain tissue. A greater sphere is used to limit the field domain.
The second model (Fig.2) has three spherical layers: skin, bone and brain. They are represented by three concentric spheres.

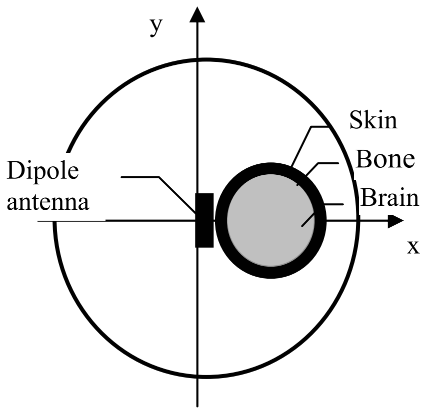


Fig.2 Three layers human head models

Table 1 comprises the geometries, the electric parameters (the relative permittivity ε_r and the electric conductivity σ) and the mass densities for the tissue layers at 1710 MHz.

Tissue	r[m]	ρ [kg/m^3]	σ [S/m]	ε_r
Skin	0.1	1100	0.941	38.2
Bone	0.095	1200	0.285	12
Brain	0.090	1050	1.521	51.8

Table 1 Parameters of the tissue layers at 1710 MHz

The antenna is placed at 5 mm from the head models. The considered radiated power is 125 mW [5], [6]. The antenna edges were modeled as perfect electric conductors.
On the boundary of the head and on the layers boundaries natural boundary conditions are imposed. On the outside edge a scattering boundary condition is set [12].

		Local peak SAR values[W/Kg]			Absorbed power[mW]		
		2d fem	Green mom[5	fdtd [5]	Green mom[5	fdtd [5]	2d fem
Homo-genous model	C	22.69	24.31	25.34	112.75	113.54	90.74
	A	23.59	24.73	25.32	114.84	114.94	100.9
3 layers model	C	9.81	13.88	15.51	119.01	117.63	116.6
	A	10.75	14.09	15.17	117.27	116.95	111.3

Table 2 Comparative local peak SAR values and absorbed power values

In Table 2 the local peak SAR values and the absorbed power levels for both adults and children, are compared.
The solution convergence was tested by using different mesh densities as well as different elements type (Lagrange quadratic, Lagrange cubic, Lagrange quartic, and Lagrange quintic).
Both different mesh densities and element types didn't affect significantly the SAR values. It can be observed that close local values of maximum SAR are observed in adult and children head models.
The total radiated power is the sum of the absorbed power and the boundary integral of the power outflow. It can be noticed that the absorbed power computed with finite element method represents about 72%-93% from the total power radiated by the dipole antenna.
The 2D models results were compared with 3D modeling results from literature [5], where Method of Moments and finite difference time domain method(FDTD) were used, using a helical antenna but radiating the same power, 125 mW.
The peak SAR values and the absorbed power for the helical antenna are higher because of the better field concentration. It can be noticed from Table 2 that the

values from the 2D models are the same order as the 3D models. But the execution time and the memory resources are significantly reduced. This indicates a certain efficiency of the 2D fem models.
In Fig.1 the SAR distribution in both adult and children homogenous head models is presented.
A certain SAR high value area can be observed at the surface of the head, in front of the antenna, where the incident wave acts.It can be noticed that this area is bigger for the children head models, because of the smaller radius .

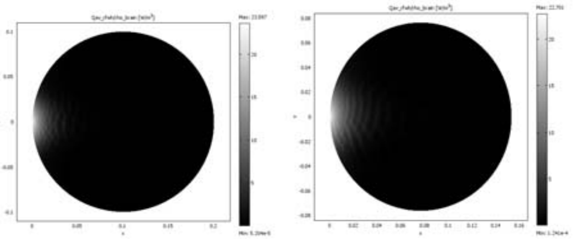
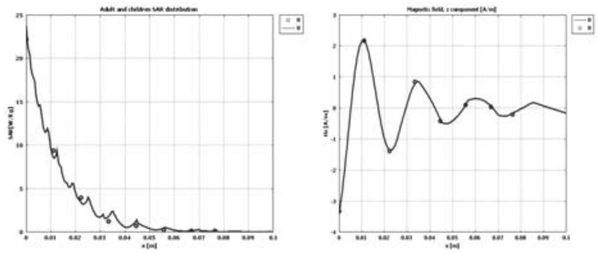


Fig.1 Surface SAR distribution for homogenous models

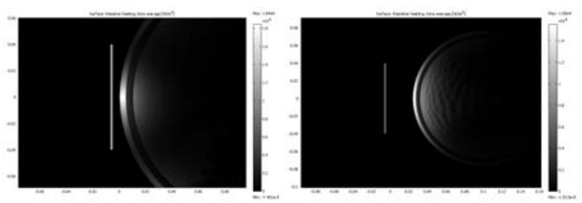
In Fig.3.a the SAR distribution over Ox, from "left year" toward the center of the model is presented. and it confirms the local peak SAR values proximity.



a b

Fig.3

In Fig.3.b the damping of the magnetic field H_z component is described (continuous curve is for adults and the circles markers for the children).



a. Adult b. Child

Fig.4 Resistive heating, time average distribution

As it can be seen from Fig.4 the skin layer concentrates a great amount of the absorbed electric power whereas the bone layer shields the electric field penetration.

3.2. Six-layers spherical 2D model

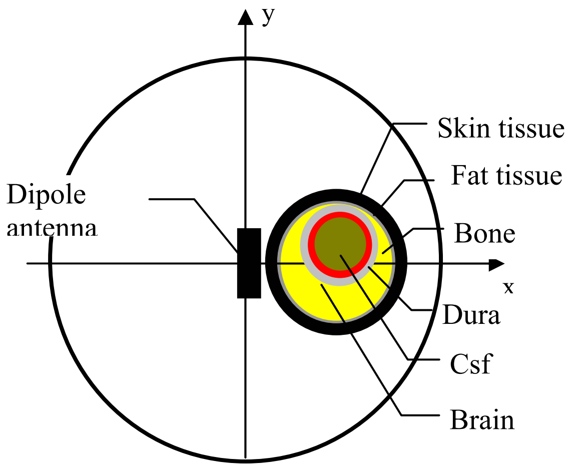


Fig.3 Six layers human head model

The tissues considered for this model are: skin, fat, bone, dura, cerebro-spinal fluid (csf) and brain.
The model is represented by two eccentric 3-layers spheres (Fig.3).
In Table 3 includes the geometry, the electric parameters(the relative permitivitty ε_r and the electric conductivity σ) and the mass densities for the tissue layers at 900MHz and 180 MHz.

Tissue layer	Radius [m]	Density [Kg/m^3]	Conductivity σ [S/m]		Permittivity ε_r [F/m]	
skin	0.09	1100	0.87	1.18	41.4	38.9
fat	0.0893	920	0.11	0.19	11.3	11
bone	0.0877	1850	0.14	0.28	12.5	11.8
dura	0.0672	1050	0.96	1.32	44.4	42.9
csf	0.0667	1060	2.41	2.92	68.7	67.2
brain	0.0647	1030	0.86	1.27	46.5	43.9

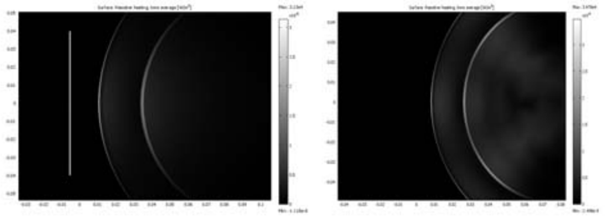
Table 3 Six layers tissues parameters

In Table 3 the local peak SAR values for each tissue layer, both adult and children head models are presented.

Tissue layer	900 [MHz]		1800 [MHz]	
	Adult	Child	Adult	Child
skin	28.457	32.497	35.68	49.2
fat	4.30	3.331	7.267	9.63
bone	2.576	1.975	7.652	7.12
dura	5.347	6.693	9.467	8.844
csf	13.062	16.522	20.49	19.113
brain	4.563	6.986	8.969	8.255

Table 4 Peak SAR values for tissue layers

It can be noticed that, as for three layers head models, the skin concentrates a great amount of the absorbed electric power together with the csf layer.



a. Adult b. Child

Fig.4 The resistive heating, time average distribution

The SAR distribution from Fig.4 validates this observation. Also the shielding effect of the bone layer is emphasized.

4 Conclusion

In this paper some aspects concerning the finite element modeling of the interaction between the EMF radiated by a dipole antenna and certain 2D human head models are described.

Finite element simulations for six spherical human models were performed, both adult and child cases.

Homogenous, three layers and six layers head models have been considered.

The local SAR peak values were similar for the adult and child respectively, at 1710 MHz.

The local peak SAR values for the six layers model, were greater for the child case, because of the smaller dimensions. The absorption qualities of certain layers were evaluated.

The results, as order of magnitude, were compared with 3D models from the literature and a good agreement has been found. This proved a certain efficiency of the 2D models.

The paper represents only the beginning of a more complex evaluation of the topic using more realistic models such as real 3D geometries imported from MRI techniques. Future researches will involve also studying the heat distribution in the head models and EM – heat fields coupled problems.

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