Analysis of Proposals to Reduce SAR Levels from GSM Terminals

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Abstract — **Is Wireless Communication dangerous? In recent years some scientists and lay people have expressed alarm at the possible harm mobile phones could cause to the user's health, even cancer. Handset terminals must meet standard limits based in SAR measurements. In this paper we present several proposals to minimize SAR values computed over a numerical user's head model using absorbent materials and new generation antennas.**

I. INTRODUCTION

The widespread use of hand-held mobile phones (Fig. 1) means that many people all over the world routinely place little Radio Frequency (RF) transmitters against their heads. The microwave region of the Radio Frequency Spectrum supports a substantial portion of the networks for communication with mobile users and for access to interactive multimedia services. Future developments in technology and services would likely place their activity in higher frequencies, and the concept of global services provided in global wireless networks, is not far away. In fact, 3rd Generation Mobile Telephony, Bluetooth technology, etc. are systems we actually hear about.

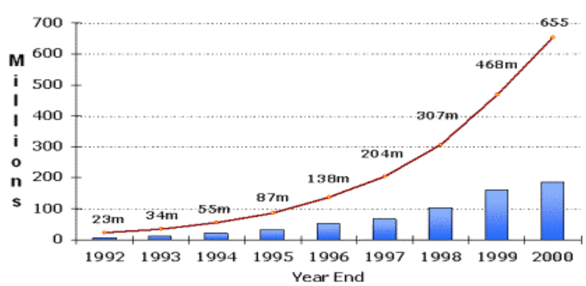

Fig. 1. World cellular subscribers growth and estimate to Dec'00. Blue bars represent in-year net gains.

Even though it is noted that research to date has produced a wide literature base, which is used by several governments and international organizations for developing safety standards and exposure guidelines to minimize harmful health impact, they are frequently contradictory.

Wireless communication terminals operate at several frequencies, depending on the State and the system used. For the United States, cell phones operate in two main frequency ranges: the older system near 850 MHz and the new PCS near 1900 MHz. European mobile terminals use the Global System for Mobile Communications (GSM), operating near 900 MHz and 1800 MHz. Fortunately, Energy in this frequency range is called non-ionizing because the Photon Energy is insufficient to knock electrons from atoms in living tissue (a source of serious biological damage when using X-Rays or Gamma-Rays). So, the most apparent biological effects of RF Energy at cell phone frequencies are due to heating. Many other mechanisms different from heating have been pointed out, but those well enough understood to be analyzed quantitatively only produce observable effects at very high exposure levels.

Exposure Standards are then designed to give protection against all identified hazards of RF Energy, actually associated only with excessive tissue heating (Table I). This heating obviously depends on the power emitted by the mobile terminals, which varies from 600 mW in analog hand-held phones, to 125 mW in many digital models (in this last case, the output power is adaptively controlled by the base station), but also on the electrical properties of the living tissues at the working frequencies.

This paper presents several results obtained by comparing these Standard Limits against a numerical model of a user's head and a simple hand-held terminal operating at the GSM frequencies, using MAFIA v4.014 software. We have developed a simple method for reducing the amount of Energy absorbed by the modeled tissues by placing several absorbent structures around the terminal's antenna, and by implementing specific 1800MHz-band shorted microstrip patch antennas.

II. NUMERICAL MODEL DEFINITION

Specific Absorption Rate (SAR) is the current parameter used by government regulatory agencies to determine compliance with non-ionizing radiation hazard standards. This parameter tries to measure the amount of Electromagnetic Energy absorbed by a specific living tissue, and it is related to the Electric Field (1).

TABLE I

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STANDARD LIMITS IN U.S.A., EUROPE AND JAPAN

SAR Standards	***ANSIC95.1-1992***	***prENV50166-22***	***TTC/MPT***
Whole body averaged SAR	*0.4 W/Kg*	*0.4 W/Kg*	*0.4 W/Kg*
SAR peak value	*1.6 W/Kg*	*2 W/Kg*	*8 W/Kg*
Time average	*30 minutes*	*6 minutes*	*6 minutes*
Space average (cubic volume)	*1 gr.*	*10 gr.*	*1 gr.*

The different parameters that rule the equation are the following: tissue conductivity at a specific frequency, $\sigma(x, y, z, freq)$, imaginary part of the Electric Permitivity of the tissue at a specific frequency, ε'', the Electric Field vector, $\vec{E}$, the tissue's Density, $\rho(x, y, z, freq)$ and the frequency at which the terminal operates, $\omega = 2 \cdot \pi \cdot freq$.

$$SAR = \frac{\sigma}{2 \cdot \rho} \cdot |E|^2 = \frac{\omega \cdot \varepsilon''}{2 \cdot \rho} \cdot |E|^2 \qquad (1)$$

When carrying out this study, one of the most interesting points was the different numerical models developed in each publication read. The complexity level of the numerical model was different from ones to the others [1] – [4], so we decided to introduce two different human head models, depending on the number of tissues used in each one (Fig. 2).

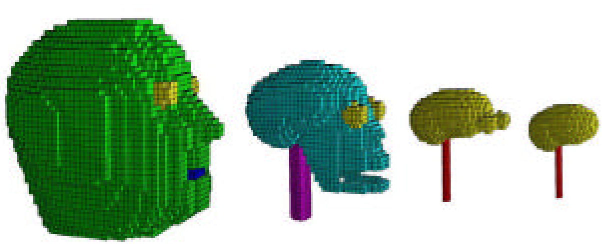

Fig. 2. User's head tissue structure.

The Simple Model only differentiated between four living tissues: cartilage, muscle, brain and eyes. The Complex Model added another four tissues to the others: vertebra, skull, teeth (they were all modeled as bone tissue) and spinal cord. All their electric properties were taken from Gabriel's [5] tissues' properties table (Table II).

We have also defined the user's hand which holds the terminal, so as to obtain measurements as close to reality as possible. The user's hand was modeled with two tissues: bone and muscle. Nevertheless, we didn't get SAR values in this structure, as we centered our study in the head tissues (Fig. 3).

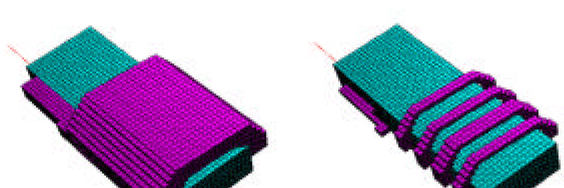

Fig. 3. User's hand holding the mobile terminal, with and without muscle tissue.

The mobile terminal was modeled as a solid metal box, and we have placed a λ/4 monopole on it which acts as a radiating element. This means that the total length of the monopole antenna was different depending on the frequency of work. We fed this monopole antenna with a parallel current generator of a continuous sinusoidal signal of peak value 0.1 A. This means that we could not use a pulsed signal as real terminal do.

TABLE II
ELECTRIC PROPERTIES FOR THE TISSUES USED

Tissue	***900 MHz*** ε_r	σ*(S/m)*	***1800 MHz*** ε_r	σ*(S/m)*	ρ *(Kg/m*^{3}*)*
Hand	*20.7878*	*0.3400*	*19.3432*	*0.5882*	*1850*
Brain	*45.8055*	*0.7665*	*43.5449*	*1.1531*	*1030*
Cartilage	*42.6531*	*0.7823*	*40.2155*	*1.2868*	*1100*
Eyes	*69.9018*	*1.6362*	*68.5734*	*2.0325*	*1010*
Muscle	*55.9555*	*0.9691*	*54.4423*	*1.3894*	*1040*
Skull	*16.6208*	*0.2416*	*15.5620*	*0.4317*	*1850*
Sp. Cord	*32.5310*	*0.5736*	*30.8669*	*0.8428*	*1030*
Teeth	*16.6208*	*0.2416*	*15.5620*	*0.4317*	*1850*
Vertebra	*16.6208*	*0.2416*	*15.5620*	*0.4317*	*1850*

Another point of interest was the spatial resolution of all the structures defined in our model. So as to easily implement the 1 gr and 10 gr average SAR algorithms, we used a uniform mesh of 0.52 cm side for the head model. This mesh was bigger for the zones outside the user's head volume, and more detailed (0.26 cm side or even 0.13 cm side) around the mobile terminal and the user's hand model, depending on the elements coupled to the terminal. This means that the evaluation of miscrostrip antennas, defined by very small components, required a better precision around the antenna than around the rest of the terminal and the hand, different from the user's head mesh.

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II. Simulations and Results

As we said before, safety standards are based solely upon thermal considerations, and were created by engineers, rather than biologists. Many scientists believe that SAR standards should not be used because test procedures are not fully standardized and cannot measure the actual effects of radiation upon the body below the thermal level. SAR test procedures measure radiation emissions using simulations and specific equipment. These simulations are required because probes would literally have to be inserted into the head of a person while using the mobile phone, to derive accurate results.

We divided our study in three main series of simulations, each one with different goals. The first simulation series was done to analyze which are the most influent parameters when getting SAR measurements. The second series of simulations was done to minimize the SAR levels obtained in the worst case by using several absorbent materials, and even parasite non-radiating elements. Finally, the third series of simulations compared the performance of a specific microstrip antenna [6] versus the traditional monopole antenna.

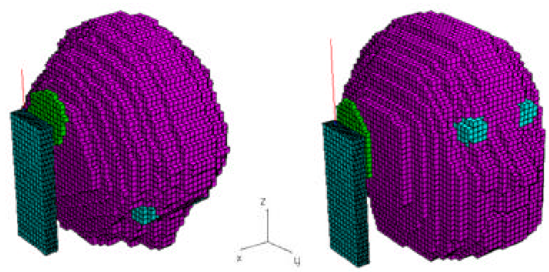


Fig. 4. User's head model in the normal usage position, and in worst case position.

For those simulations which needed the rotation of the terminal to the normal usage position (approximately 60 degrees), we decided to rotate the user's head model instead of the terminal model because of the accuracy needed for the antenna specifications when doing the mesh (Fig. 4).

Terminal's dimensions were 124.5x46.8x10.4 mm for the monopole antenna, and 120x42.5x22.5 mm for the miscrostrip antenna.

A. First Series of Simulations

The first series of simulations proved that the use of a more complex numerical model doesn't mean a great change in SAR values, and that the inclusion of the hand model does reduce SAR values but not significantly (approximately 10%) (Fig. 5).

Fig. 5. SAR peak values at 900 MHz and 1800 MHz, including the user's hand model.

The use of 900 MHz or 1800 MHz was decisive. Higher frequencies, higher proximity to the user's head, usage position and smaller size of the terminal gave worst SAR results (Fig. 6). Simulations at 900 MHz confirmed the Standard Limit but were still too close to it. Simulations at 1800 MHz, however, showed too high values of SAR for both, U.S.A. and Europe Standards.

Because of all these results, the simulations that followed used the Simple Model, without the user's hand model, with the terminal in vertical position working at 1800 MHz, and separated just 5 mm from the user's head.

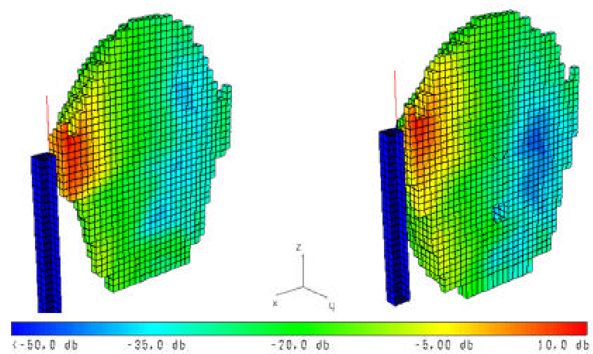
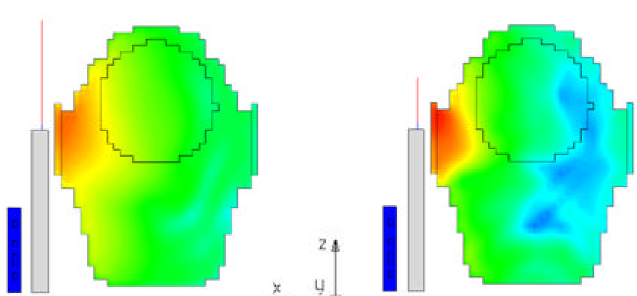


Fig. 6. SAR peak values at 1800 MHz for the Simple Model, with the terminal in vertical and normal usage position.

B. Second Series of Simulations

So as to reduce the SAR levels, we decided to use absorbent materials around the monopole antenna, and parasite elements between it and the user's head model, because the highest

TABLE III
SAR Values Obtained in the Second Simulation Series (Freq. 1800 MHz)



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SAR_{Peak} (W/Kg)	Brain		Cartilage		Muscle		Eyes	
	SAR_{1gr}	SAR_{10gr}	SAR_{1gr}	SAR_{10gr}	SAR_{1gr}	SAR_{10gr}	SAR_{1gr}	SAR_{10gr}
Stand Alone	0.1439	0.1466	7.4774	6.2669	6.0109	4.0166	0.0024	0.0027
e_r=1-0.1j	0.1174	0.1191	5.5934	4.8228	4.6296	3.1177	0.0019	0.0021
e_r=10-10j	0.5359	0.0655	2.1861	1.7011	1.4857	0.9345	0.0021	0.0025
Parasite Monopole	0.0283	0.0344	4.0099	2.6747	1.8075	1.2802	0.0052	0.0056
Parasite Monopoles	0.0279	0.0347	1.8538	1.4374	1.3421	0.8245	0.0051	0.0055
Parasite Plate	0.0165	0.0191	1.2347	1.0248	0.8492	0.5609	0.0029	0.0032

levels of SAR were obtained in those tissues next to the radiating element

We used several configurations for the dielectric elements, varying its shape (half a cone, half a cylinder and an angular section of a cylinder). These structures could be placed next to or 2 mm from the monopole antenna, which obviously modified their thickness.

For these simulations we used two different dielectric materials: e_r=1-0.1j and e_r=10-10j.

For the parasite elements, we placed a single parasite monopole, two parasite monopoles and a thin metal plate. All of them were placed at the edge of the terminal, next to the user's head model (Table III).

B. Third Series of Simulations

As a final step in our analysis, we decided to test the performance of the new microstrip antennas developed for hand-held terminals. In this case, we implemented two patch microstrip antennas as presented in [6].

TABLE IV

SAR VALUES OBTAINED IN THE THIRD SIMULATION SERIES (FREQ. 1800 MHZ)

SAR_{Peak}	Cartilage			Muscle		
	Alone	Single Patch	Stacked Patch	Alone	Single Patch	Stacked Patch
SAR_{1gr}	1.459	0.198	0.075	1.399	0.162	0.064
SAR_{10gr}	1.365	0.250	0.097	1.176	0.181	0.074

The need for a specific mesh, and the difficulty in modeling them with MAFIA meant that the time to get the SAR values was increased enormously. Results, however, were much better (Table IV).

V. CONCLUSION

The results of this study apply to non-pulsed signals and to non-dielectric modeled terminals. The main conclusions can de resumed as follows:

- No standardized method for evaluating SAR Levels has been approved yet.
- SAR Limits were exceeded in all cases when working at 1800 MHz, but reduced with our proposals.
- Microstrip antennas showed the best results.
- Monopole antenna performance must be seriously analyzed when using absorbent and parasite elements.
- More epidemiological and biological studies are needed for better defining new Safety Standards.

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