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Three-Dimensional Modeling For Heat Transfer *In The Human Brain, While Subjected To Mobile Phone Radiation*

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***Abstract**: Several computational models are introduced here for the study of microwaves penetration in the human head, when exposed in the near field of an antenna, in conditions specific to mobile telephony. Monopole and patch antennas are integrated into a conventional cell phone device and normalized exposure conditions are simulated. The generic human head considered here reproduces in shape and dimensions the Specific Anthropomorphic Mannequin (SAM), in order to be comparable with the experimental phantom. Differences in head structure and in cell phone design lead to different absorption paths and quantities of energy, which are estimated here. The numerical 3D models presented in the paper are implemented with the finite elements method (FEM). Theyare are built as simulation tools, intended to complement experimental measurements, usually performed for the compliance testing and certification of hand-held devices that act as microwave emitters in close proximity to the ear.*

Keywords: finite element method, microwaves, mobile phone emissions, numerical dosimetry, SAR computation.

I. INTRODUCTION

Certification of mobile communication devices, prior to placing them on the market, requires careful assessment testing, performed by accredited laboratory, specialized for the determination of the Specific energy Absorption Rate (SAR). Regarding the domestic market of mobile phones, the state is in the position to protect the safety and health of the citizens, in their position of consumers, according to EU Recommendation 1999/519/CE , which is also transposed into national legislation. A specialized laboratory, fully equipped for SAR measurement in agreement to international standards was recently opened as a high performance facility, authorized to perform conformity assessment tests regarding the electromagnetic emissions of cellular phone terminals. The access to efficient experimental equipment designed for SAR measurement and the availability of commercial software for numerical analysis of high frequency electromagnetic radiation, does not ,however, provide for an unconditional solution to the electromagnetic field (EMF) dosimetric problem. The energy absorption in human tissue is highly dependent on several characteristics that have to be considered in the experimental and/or computational approach:

* *the anatomical domain* – characterized by shape, inner nonhomogeneous structure, relative position in relation with the radiation source, electric properties of the biological tissues (variable with the frequency, with the hydration level, variable in the living compared to nonliving state of the body and thus difficult to be determined by measurements);
* T*he characteristics of the radiation source* – signal waveform and frequency band, emitted power, polarization of the electromagnetic emitted wave, continuity, antenna type and its positioning inside the hand-held device;
* *The physical aspects* of defining the dosimetric quantities (i.e. *SAR* for the study presented here) – the procedure of measurement and computation, the averaging techniques over space and time;
* *The ratification procedure* - the dosimetric quantities determined on the spot (either experimentally or numerically) should be compared with reference specifications in guidelines and standards.

The investigation program presented here points to the experience and know-how acquired by the research team, for setting in work a complex assembly dedicated to dosimetric analysis in the field of high frequency nonionizing electromagnetic radiation, with reference to the normative frame. The dosimetric analysis assembly combines, in a complementary manner, a sophisticated measurement equipment and a flexible numerical mode.

II. EXPERIMENTAL SAR LABORATORY

A. *Nonionizing radiation dosimetry*

The specific absorption of energy (d*W*/d*m*) in a lossy dielectric material exposed to high frequency EMF is currently related to the increase in

Temperature(T) and it is usually quantified by the *Specific energy Absorption Rate*, defined

$$SAR = \frac{d}{dt}\frac{dW}{dm} \text{ or } SAR = C\frac{dT}{dt} = \sigma E^2/\rho [w/kg]$$

where d·/d*t* denotes the rate of a certain physical quantity, *E* represents the *rms* value of the inner electric field strength; *C*, and ρ are the physical properties of the material: specific heat capacity, electric conductivity and mass density. *SAR* is also the quantity measured during the tests performed for the certification of electronic wireless equipment, because it is referred to as a *basic restriction* in international norms for limiting human exposure to microwaves. Two limiting levels are specified: a lower value for the exposure averaged over the entire human body and a higher value applicable for the local exposure of a particular vulnerable area of the body (for example the head). It is supposed that the restricted *SAR* values are averaged over time and space, as Table 1 shows.

TABLE I
STIPULATION ON *SAR* IN INTERNATIONAL STANDARDS AND GUIDELINES

	Averaged whole body SAR	Localized SAR (head and trunk)	Averaging time
Europe [9]	. 0.08 W/kg	2 W/kg averaged over 10 g of tissue 6 min	6 min.
USA * [8]	0.08 W/kg	1.6 W/kg averaged over 1 g of tissue 30 min.	30min.

* in 2005 was issued a revised version of [8] which is harmonized with[9].

Since it is harmful to measure *SAR* directly in the human body, the standard procedures make reference to the use of phantoms and state specific experimental protocols aimed to ensure the best compliance to reality. The referred normative, adapted to the mobile phones fabrication in different world region are not identical; they are however harmonized. The most important aspects are the requirements on the measuring method and on the measurement accuracy provided by the test system. A special characteristic of both standards resides in the explicit and detailed provision for the measurement uncertainty; the limit of the maximum permissible uncertainty is about 3dB.

B. SAR measurement laboratory

The test equipment presented in Fig.1 includes the device under test (DUT), i.e. the cell phone, the positioning and scanning system for the DUT and for the electric field probe, the calibration systems for the probe and for the tissue simulating substance, the command and data processing system. The phantom used for mobile phones testing is the Specific Anthropomorphic Mannequin (SAM) .

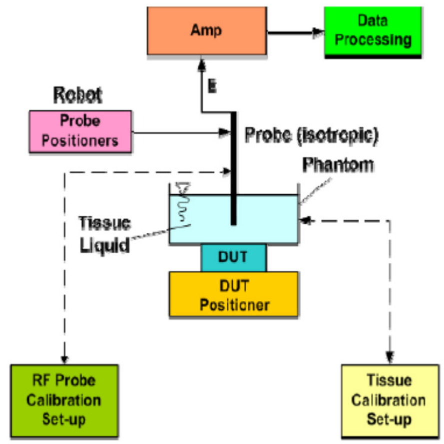

Fig 1. Block diagram of the equipment

Phantom enclosure and the liquids simulating the head tissue or other human body tissues are subjected to some strict requirements; when the frequency band of the mobile phone is changed the liquid should be changed accordingly, due to the working frequency influence on its dielectric properties.
The robot for field probe positioning must be able to scan the whole volume subjected to exposure with a view to achieving a three-dimensional measurement of *SAR* with a remarkable positioning accuracy of □0,2 mm. The miniature field probes have a special construction and very high linearity. The electric field probe is of three axes type (3D) and it can scan the phantom volume from a minimum depth of 4mm, measured from its bottom. The system available for our research is the commercial COMOSAR Satimo test bench that works with the monitoring and data processing OPENSAR software; the whole measuring system operates in an electromagnetically shielded room. Fig. 2 presents the experimental setup (left) and the phone-positioning device holding the cell phone near the SAM phantom (right).
The laboratory for *SAR* dosimetry is designed to perform measurements for all types of mobile phones existing on the market: CDMA, GSM 900/1800, WCDMA, UMTS etc. covering a frequency band from 450 to 2450 MHz.

III. NUMERICAL MODEL FOR DOSIMETRIC ANALYSIS

A 3D computational model, based on the finite elements method (FEM) was designed for the study of microwaves penetration in the human head, when exposed in the near field produced by a mobile phone device. Previous analysis of different FEM numerical models, either based on simplified geometry or built through numerical reconstruction from CT scans, led us to the head model used in this study.

The model was carefully designed to mimic the adult human head, with normal size and realistic shape, comparable to SAM, as described by the document referred in [3]. Recent literature offers a variety of studies performed with anatomical realistic numerical models [10-13]; however, the multitude of the documented versions reveals an inconvenient dispersion in the choice of physical and numerical details, that makes the comparison and the synthesis of conclusions very difficult. These circumstances support our efforts to build and evaluate our own FEM model, similar to SAM configuration, which is designed to perform numerical tests, complementary to experimental dosimetry and certification protocols. The model, implemented and processed with a commercial finite element software package, has the main quality of being available and accessible regarding our resources. Its concept is flexible and open to adjustments toward the design of different radiation sources.

IV. MODELING IN COMSOL

That data file was created from a magnetic-resonance image (MRI) of a human head; these images contain 109 slices, each with 256-by-256 voxels. The use of the variation of the data in this file on the tissue material parameters has no scientific background, and this model simply implements it to illustrate a variation in conductivity, permittivity, and perfusion rate as a function of the position inside the head. The model reduces the resolution of the volumetric data to 55-by-50-by-50 interpolation points, which matches the mesh-element density inside the head. Prior to generating the data file, the modeler in this case scaled, translated, and rotated the 3D MRI data to match the form of the imported head geometry in COMSOL Multiphysics.

A. WAVE PROPAGATION:

The radiation comes from a patch antenna placed on the left side of the head. A line current on an edge acts as an equivalent current source feeding the two patches of the antenna. To avoid reflections, the model makes use of PMLs (Perfectly Matched Layers). The model solves the vector-Helmholtz equation everywhere in the domain for a certain frequency

$$\nabla \times \frac{1}{\mu r} \nabla \times E \text{-k2}\varepsilon_r \text{E=0}$$

where μr is the relative permeability, $k0$ is the free-space wave vector, and εr is the permittivity.

TABLE II

The interpolation function samples

PARAMETE R	FREQUENC Y	VALUE	DESCRIPTIO N
σ	835 MHz	1.35 S/m	Conductivity
εr	835 MHz	56	Relative permittivity

B. HEATING OF THE HEAD

The bioheat equation models the heating of the head with a heating loss due to the blood flow. This heat loss depends on the heat capacity and density of the blood, and on the blood perfusion rate. The perfusion rate varies significantly in different parts of the human body, and the table below presents the values used here.

TABLE III

The perfusion rate at different parts of body

PART	PERFUSION RATE
Brain	2·10-3 (ml/s)/ml
Bone	3·10-4 (ml/s)/ml
Skin	3·10-4 (ml/s)/ml

The same interpolation function used for the electric parameters also models the difference in perfusion rate between the brain tissue inside the head and the outer parts of skin and bone. Note again that the use of the interpolation function does not have any physical relevance; it is just to show a realistic effect of a varying material parameter.

V. SIMULATION RESULTS

The design was simulated with the help of COMSOL multiphysics 4.3 and analyzed for various parameters such as frequency, distance between ear and patch antenna in order to improve the SAR.

The model studies the local SAR value in the head using the formula described earlier for the frequency 835 MHz. The SAR value is highest close to the surface of the head facing the incident wave. The differences in electrical properties become visible if you plot the local SAR value on a log scale (Figure 3). The bioheat equation produces a similar plot for the heating of the head, which is highest closest to the antenna. The maximum temperature increase (from 37 °C) is less than 0.2 °C, and drops rapidly inside the head.

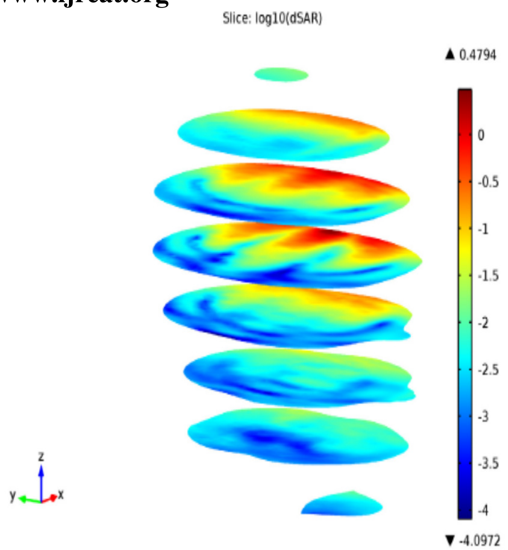

Fig3, Log-scale slice plot of the local SAR value.

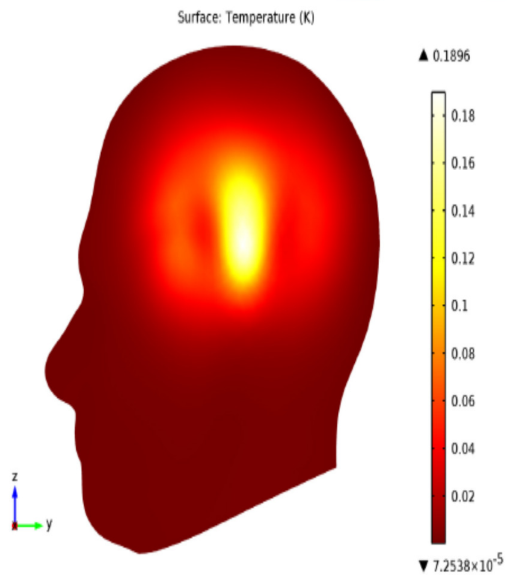

Fig 4. The local increase in temperature at the surface has a maximum of 0.193 °C right beneath the antenna

VII. CONCLUSION AND FUTURE WORK

In this study, we analyzed the effects of EM field exposure to human head from patch antenna. Our interest was focused on SAR evaluation and temperature increase due to EM-wave propagation. Based on numerical simulations carried out with FEM based approach, interaction between EM field and head model has been investigated. For this reason, different scenarios have been implemented. The proposed method provides a good overall accuracy in determining these effects, as our simulations demonstrate. Numerical models remarked that the distance between antenna and user is the most important parameter for determining the intensity of SAR and temperature increments as well as the exposed area of the human head. Within this framework, we have analyzed field penetration: the radiation penetrates till 1 [cm] of deepness, especially when the antenna is positioned in front of the user (in this case, the eyes, for their composition, are the organs that absorb most part of radiation). Anyway, results of our simulations never overcame the thresholds imposed by international laws. The proposed study shows preliminary results, since we consider general cases. Further improvements could analyze particular situations and investigate other wireless technologies using different frequency ranges, in order to establish the impact on human safety.

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