SAR AND THERMAL EFFECT PREDICTION IN HUMAN HEAD EXPOSED TO CELL PHONE RADIATIONS

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ABSTRACT: *The wide deployment of cellular communications technologies make the cell phone one of the common sources of radio frequency(RF) radiations that cause in concerns about the probable health effects due exposure to RF radiations. As cell phone is usually hold next to the head of the user during conversations, hence, much attention must be paid to investigate the health effects produced due to interaction of head tissue with cell phone radiations. This aim of this work is to the implications of cell phone usage on human head through the use of a human head model that composed of multi layers. The human head model was simulated to evaluate the Specific Absorption Rate (SAR) and determine variation within the head exposed to RF radiations from the cell phone operating at 900 MHz.*

Keywords: Electromagnetic radiation, Specific absorption rate (SAR), Human head modelling, RF thermal effects on human head. Penetration depth.

I. INTRODUCTION

The colossal benefits of the communication services presented by cellular technology result in explosive increase in the number of people using cell phones [1]. The known effect of exposure to electromagnetic microwave frequencies used in mobile communications is the thermal effect. This has caused growing concerns about the probable adverse health effects produced due to the exposure to radiations emitted by cell phones especially because these sources are usually placed close to the human head [1,2].

Placing cell phones close to user's head during calls may affect the human brain that have very sensitive tissues to temperature increase[2.3].

The RF thermal effects investigation can be usually done either by using computer modeling techniques with the help of Finite Difference Time Domain (FTDT) computations or by using of phantom model of a human body. Both approaches cannot be easily applied and cannot evaluate the exact the RF

thermal effect in natural biological tissues as there are still many unknown facts about the human body.

Therefore, it is very necessary to try a simple reliable approach for human head and the RF source simulation [4,5,6].

The objective of this paper is to investigate the thermal effects of the electromagnetic radiation induced inside the human head theoretically through the construction of an approximated simplified numerical models for the human head. The intensity of the penetrated electric field and the head tissue properties will be used for Specific Absorption Rate (SAR) prediction and to check compliance with safety limits. In this study, the physical quantities used to evaluate the thermal effect produced due to RF exposure is presented in section 2. Section 3 presents the proposed human head model. Section 4 describes the steps of model simulations to determine SAR and temperature in head tissues. Section 5, concludes the paper.

II. RF RADIATION THERMAL EFFECTS

The thermal effect of the radiations generated by cell phones within the brain tissues is usually quantified by power density (electromagnetic field components) around the head and the Specific Absorption Rate (SAR). The power density (S) propagated around the exposed user head located at the free space distance r from the cell phone antenna measured in watts per square meters, can be expressedas.[7]

$$S = \frac{P_t \, G_t}{4 \pi r^2} = \frac{{E_i}^2}{\eta} \qquad (1)$$

Where Pt is the transmitted power, Gt is the transmitting antenna gain, Ei is the electric field intensity induced inside the tissue layer (V/m),, and η is the tissue layer impedance(Ω). The electromagnetic field (EMF) produced by the cell phone during a call, penetrate inside the exposed human head via skin. The depth at which the incident power density inside the penetrated object is reduced by a factor of e–2 compared to its magnitude at the head surface is called penetration depth. Consequently, the electric field intensity (Ei) at a depth distance, z, due to the incident field Eo, on the head surface is given as. [8]

$$E_i = E_o \, e^{-z/\delta} \qquad (2)$$

Where δ, is the skin depth in any material that can be given by[7].

$$\delta = \frac{1}{\omega} \sqrt{\frac{2}{\mu \varepsilon}} \left[\sqrt{1 + \left(\frac{\sigma}{\omega \varepsilon} \right)^2} - 1 \right]^{-0.5} \qquad (3)$$

$$\omega = 2 \pi f, \quad \mu = \mu_o \mu_r, \quad \varepsilon = \varepsilon_o \varepsilon_r, \quad \eta = 377 \sqrt{\mu_r / \varepsilon_r} \qquad (4)$$

where ω is the angular frequency, f is the frequency, σ is the conductivity, μ is the permeability, μo is the permeability of vacuum, μr is the relative permeability, ε is the permittivity, εo is permittivity of vacuum, and εr is the relative permittivity .The absorbed energy leads to heat the head tissues at different rates depending on phone type, exposure time, and tissue properties [8]. The amount of heat quantity absorbed by the human head can be given as [7] [9].

$$\Delta Q = c\ m\ (\Delta T) \quad (5)$$

where Q is the heat energy absorbed or dissipated in joule (J), m is the mass of the substance(kg), ΔT is the change in substance temperature(°C), c is the specific heat of the substance i.e., the heat required to change a substance unit mass by one degree measured in J/(kg.°C) or J/(kg.°K).

The power absorbed per unit mass of tissue exposed to RF radiation i.e., the specific absorption rate (SAR) is the other dosimetric quantity used to evaluate the energy absorbed by human tissue due to exposure to RF source, RF thermal effect investigation, and RF exposure limits set.SAR expresses the time derivative of absorbed energy per unit mass of tissue exposed to RF radiation. It can be expressed as [10,11] .

Table1. Tissue Layers Characteristics [12-13-14-15]

Tissue	Layer Thickness mm	Heat Capacity J/kg.C	900 MHz εr	900 MHz σ(S/m)	1800 MHz εr	1800 MHz σ(S/m)	2100 MHz εr	2100 MHz σ(S/m)	Mass Density (kg/m3)
Skin	1.00	3662	43.74	0.855	43.85	1.23	38.43	1.30	1100
FAT	0.14	2400	05.46	0.051	11.02	0.19	5.32	0.09	0920
SKULL	0.41	1256	12.45	0.143	15.56	0.43	15.28	0.50	1850
DURA	0.50	3364	44.40	0.960	42.89	1.32	42.49	1.47	1030
CSF	0.20	4000	68.60	2.410	67.20	2.92	66.76	3.15	1030
BRAIN	81.0	3650	52.73	0.942	43.54	1.15	43.05	1.31	1050

$$SAR = \frac{\partial}{\partial t}\left(\frac{\partial Q}{\partial m}\right) = \frac{\partial}{\partial t}\left(\frac{c\ m\ \partial T}{\partial m}\right)$$

$$SAR = \frac{c\ \Delta T}{t} \quad (6)$$

$$SAR = \frac{\sigma\ E_i^2}{2\rho} \quad (7)$$

Where

Ei is the r.m.s value of the electric field strength induced inside the tissue (V/m), σ is the tissue conductivity in (S/m), t is the exposure time in seconds, and ρ is the tissue mass density (kg/m^3). Equations 6 and 7 imply that the SAR value of tissue depends on the induced electric field intensity, the exposure time, and the tissue electrical- thermal properties. The energy absorbed by the biological tissue is converted to thermal energy causing to increase the temperature. Penne's bio-heat equation is usually used to determine heat transfer in living tissues [12].

III. HUMAN HEAD MODEL CONSTRUCTION

Assuming a uniform spherical head shape, the human head can be modeled by a simplified spherical multi layered structure as illustrated in Figure 1. The proposed head model is composed of six isotropic homogeneous lossy dielectric layers with different properties.T he multi- layer head model is assumed to be composed of skin, fat, skull, Dura, cerebro-spinal fluid (CSF), and brain layers. Setting the thickness and electrical-thermal properties of human head tissues corresponding to each RF source frequency is difficult as there is a significant diversity of their values among published studies and because of their dynamic nature. The model considered the layer properties presented in Table

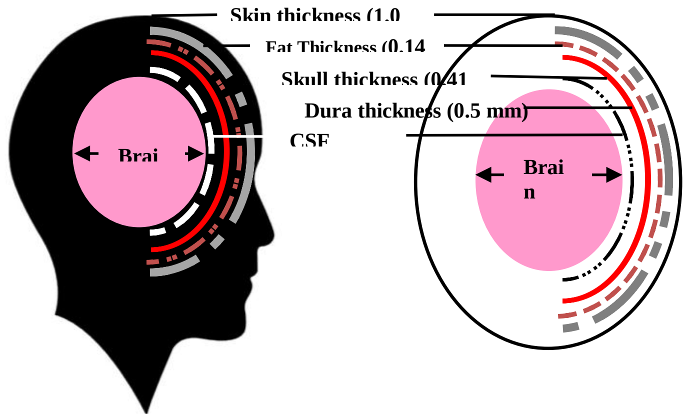

Figure 1. Human Head Model

1[12-15].

The cell phone (RF source) that operates in transmit mode (up-link) was set at a distance of 2.0 cm from the skin layer of the human head. The cell phone antenna is assumed to transmit in an isotopic mode around the human head with a unity gain
 (G_t = 1).

Table 2. SAR Calculated in Human Head Layers for GSM-900 Cell Phone

Tissue	Layer Radius (mm)	Impedance Ω	E V/m	Density (kg/m^3)	SAR (W/kg)
Skin	83.25	57.00355	14.528	1100	0.11320
Fat	82.25	161.3411	24.441	920	0.01650
Bone	82.11	106.8456	19.890	1850	0.01529
Dura	81.70	56.57829	14.4738	1030	0.09762
CSF	81.20	45.51759	12.9822	1030	0.19717
Brain	81.0	51.91734	13.8648	1050	0.08623

IV. SAR-THERMAL DISTRIBUTION

The median up-link frequency in a globa system for mobile communication (GSM) can be calculated to be 902.5 MHz and 1747.5 MHz for GSM-900, and GSM-1800 respectively. While it was calculated to be 1950 MHz for Universal Mobile

Telecommunications System (UMTS) or so-called third-generation (3G) systems [15,16].

The depth at which the transmitted RF signals penetrate the human head was calculated for each layer and at different frequency bands. The average penetration depth was calculated to be 5.33cm, 5.404 cm, and 4.128cm at GSM-990 GSM-1800, and UMTS cell phone respectively.

In (GSM) systems that apply time division multiple access (TDMA), eight users can share the same channel. The maximum transmit power of GSM-900 phone is 2W, therefore, the average power transmitted will be only one-eighth of the time (2W/8=0.25W). The maximum transmit power of the

GSM-1800 phone is 1W, and the average power transmitted 0.125 W.In the following, illustrative calculations the induced electric, SAR, and the temperature rise and their variation along the diameter of the model due to exposure to GSM-900 cell phone radiations will be presented in details. SAR of GSM-1800 and UMT cell phones will be summarized .The power density around the head exposed to the cell phone that is 2.0 cm away from the head skin was calculated as

$$S = \frac{P_t\ G_t}{4\pi d^2} = \frac{0.250\times 1}{4\pi\ (0.02+0.0533)^2} = 3.7027\ W/m^2$$

The prediction of cell phone signal propagation and absorbed power rates in each tissue layer in the head requires to determine the propagation medium impedance. Assuming that the relative permeability (μr) of head tissue is equal to one, the impedance (η) of all layers can be determined by the relation ($\eta = 377\sqrt{1/\varepsilon_r}$). Furthermore, the field induced and SAR in each layer can be determined with the help of the relation ($E = \sqrt{S\ \eta}$).

$$\eta_{skin} = 377\sqrt{1/43.74} = 57.003\,\Omega$$

$$E_{skin} = \sqrt{S\ \eta} = \sqrt{3.7027\times 57.003558} = 14.528\,V/m$$

$$SAR_{skin} = \frac{\sigma\ E^2}{2\ \rho} = \frac{0.855\times(14.528)^2}{2\times 1100} = 0.1132\,W/kg$$

The mass of each layer was calculated considering their radius and mass density to determine the percentage representation of each living tissue layer in a unit mass (1.0 kg) of the human to use it in SAR calculation.

$$\textit{Brain volume} = (4/3)\ \pi\ (8.1^3 - 0) = 22260949\,cm^3,\quad mass = 2.4487044\,kg$$

$$\textit{CSF volume} = (4/3)\ \pi\ (8.12^3 - 8.1^3) = 16.528966\,cm,\quad mass = 0.0152066\,kg$$

$$\textit{Dura volume} = (4/3)\ \pi\ (8.17^3 - 8.12^3) = 41.682651\,cm^3,\quad mass = 0.0771129\,kg$$

$$\textit{Skull volume} = (4/3)\ \pi\ (8.211^3 - 8.17^3) = 34.565897\,cm^3,\quad mass = 0.0356028\,kg$$

$$\textit{Fat volume} = (4/3)\ \pi\ (8.225^3 - 8.211^3) = 11.879409\,cm^3,\quad mass = 0.0122357\,kg$$

$$\textit{Skin volume} = (4/3)\ \pi\ (8.325^3 - 8.225^3) = 86.050317\,cm^3,\quad mass = 0.0903528\,kg$$

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$$\textit{Skin volume} = (4/3)\ \pi\ (8.325^3 - 8.225^3) = 86.050317\,cm^3,\quad mass = 0.0903528\,kg$$

The total mass of the head in our model was calculated as 2.6792152kg. The SAR with one kilogram can be calculated to be:

$$(SAR)_{Head} = \frac{2.4487044}{2.6792152}\times 0.11320 + \frac{0.0152066}{2.6792152}\times 0.01650 + \frac{0.0771129}{2.6792152}\times 0.01529 + \frac{0.0356028}{2.6792152}\times 0.09762 + \frac{0.0122367}{2.6792152}\times 0.19717 + \frac{0.0903528}{2.6792152}\times 0.08623$$

$$(SAR)_{Head} = 0.1090997\,W/kg$$

Figure 2 shows the variation of the electric field intensity induced inside the human head skin layer for different depth distances from GSM-900 phone radiation. It can be noticed that as depth distance increased along the head diameter, the field will be exponentially decreased, and the SAR will be decreased.

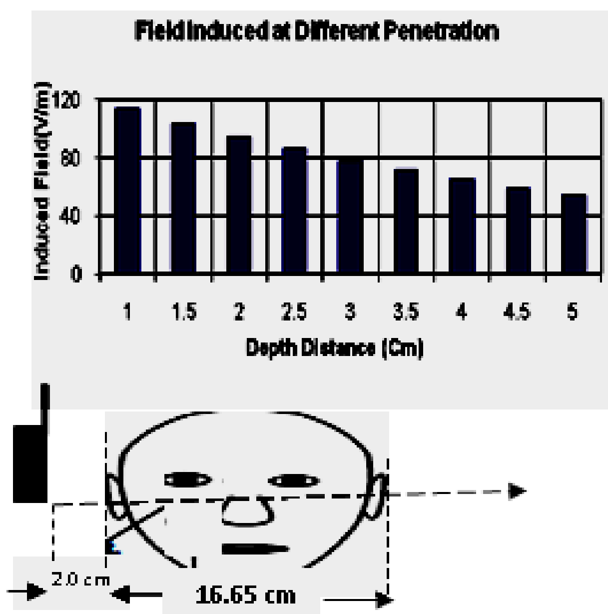

Figure 2. Field Induced in Human Head

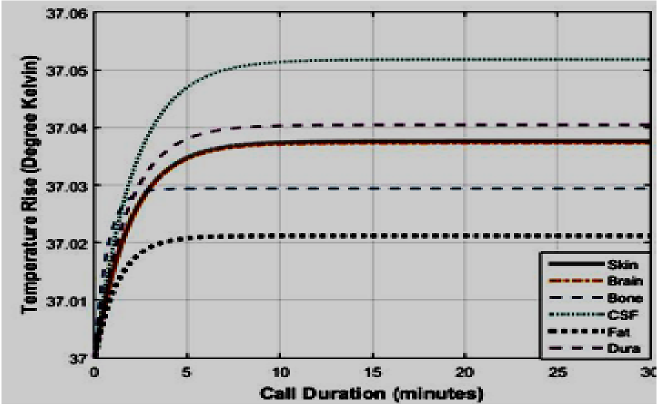

Figure 3. Temperature in Human Head with Time

Figure 3 illustrates the tissue temperature along a period of 30 minutes. It shows that the temperature in all layers increases exponentially during the first few minutes. After 300 seconds, the temperature of CSF is increased by 0.047, while in the brain it increases by 0.034. This was because of their high conductivity compared with other layers. The temperature variation rate slows down after the next few minutes.

CONCLUSIONS

The concern associated with cell phone usage have evoked attention to investigating the effects of cell phone radiations on the human head. Studying the influence of tissues exposed to cell phones radiations requires to establish an approximated human head model with real structure. A simplified spherical head model with six layers was built to evaluate the absorbed energy and temperature elevation at tissues in human head tissues. The model is simulated with the GSM-900 cell phone, of an output power of 0.25W, and when the phone is located at 2.0 cm from the head skin. It has been observed that the penetrating induced field is sensitive to the tissue characteristics and the RF source frequency. The obtained results illustrate that the RF energy absorbed (SAR) is maximum at the CSF layer. This is due to higher conductivity values of CSF compared to other head layers, which means high power dissipaton within them. It is found that the tissue temperature increases exponentially during the first few minutes of RF exposure. The maximum temperature rise occurs at CSF.

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