Modelling of Mobile Electromagnetics Wave Effects on the Human Head

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Abstract. The effects on the heads of human of the electromagnetic waves produced by mobile antenna are presented in this paper. The interactions between electromagnetic energy and the human head are modelled using a COMSOL simulation and the distributions of the produced electric field and resultant temperature inside the human head are obtained. A planar Inverted-F antenna (PIFA) was adopted in this modelling. Three levels of transmitted power (0.6, 1, and 1.5 Watt) were applied in the simulation to determine any increases in temperature in the brain due to microwave radiation from the mobile antenna.

1. Introduction

Extensive demand for electromagnetic waves (EM) has developed in recent years due to the various applications created by new technologies that require large data rates transfer such as cell phones, wireless body sensor networks, the Internet of things, smart meters, military applications, medical applications, and home appliances [1]. This wide usage of electromagnetic waves has led to their impact on human and other biological systems to be examined by researchers and engineers, to develop a better understanding of the relationship between the increased use of EM waves and biological functions, particularly with regard to direct impacts on human beings and the environment [2]. Many factors must be taken into account in such research, such as whether the wave repeats within a certain time (frequency), field intensity (power) [3], reflections and scattering due to objects and knife edges, and penetration depths [4]. Two viewpoints drive such research, the first one being to find ways to preserve life from any negative EM wave effects [5] and the second one being the exploitation these waves to better serve humanity and other organic life [6].

For several decades, researchers have tried to investigate the biological effects on human health and life, of such applications, producing both a boom in positive applications such as X-rays, MRIs, and wireless communications, and evidence that unwise use of EM waves can produce non-healthy effects on human and other forms of life [7]. Specific, limited ranges of microwave frequencies are thus now used more often than others, such as cell phone frequencies that have a smaller impact on human cells within certain power ranges. This highlights the need to develop theoretical and empirical human models and biological systems to further examine the problem as a wider range of frequencies is required to prevent interference.

One of the main issues with EM waves is absorption leading to thermal heating, leading to quantitative studies on power absorption and heating and their direct relationship to internal EM fields rather than external EM waves [8]. These effects appear under various different exposure conditions for different frequencies and different types of subject [9]. Many researchers in this area have used finite difference
time domain method (FDTD) methods to combine examination of both electromagnetic and thermal interactions. Some of them also discarded the radiative cooling phenomenon during thermal simulation, while others include issue in their models to make these closer to the real world [10].

2. Microwave heating on biological tissue

Electromagnetic wave fields have a biological effect that can be viewed as a decomposition of two main contributors; these are the external effect caused by the external power density and the dielectric field inside the body. Thermal and non-thermal mechanisms are triggered by to EM fields; in response the alternating current induced at high frequency radiations, EM energy is transferred to the body when the latter is exposed to high frequency EM waves. This energy accelerates the ions in the tissue and often causes them to collide with other molecules, contributing to an increase in the local temperature and hence an increase in tissue temperature overall.

Serious thermal effects may include blindness, sterility, heating of tissues, and burns. Non-thermal effects include the alteration of the body’s circadian rhythm, alterations in the nature of the electrical and chemical signal communication through the cell membrane, possible carcinogenic effects, and interference with medical devices [11]. Increased use of cellular antennas and other RF generating devices thus raises several concerns about the potential health effect from the exposure to the resulting RF radiation; the short term effects are well known but long term effects are less well researched. Scientists studying the adverse effects of phone radiation did, however, suggest that long term mobile phone usage has led to a rise in diseases rates for issues such as Alzheimer’s disease, migraines, infertility, cancer, eye defects, and electromagnetic hypersensitivity; it can also affect human psychology, producing anxiety, insomnia, and depression [12].

3. Theory and simulation

3.1 Planar Inverted-F antenna (PIFA)

In mobile communication manufacturing and design, there is a demand for creative methods to support better operation and reduce the size of equipment. The PIFA antenna [13] is commonly been in mobile telephones, as this type of antenna offers resonance at a quarter-wavelength, reducing the necessary size of the phone handset, as well as offering good SAR properties. This antenna type offers a low profile and an omnidirectional design, as illustrated in Figure 1.

Figure 1. Schematic: PIFA antenna used to transmit electromagnetic power.

The short pin at the terminal of the antenna is employed to motivate the PIFA antenna to resonate at a quarter-wavelength. The input impedance thus controls the feed between the open and short pin ends.
3.2 COMSOL simulation

COMSOL is a cross-platform model that allows examination of physical problems based on finite element analysis. It uses either a time- or frequency domain-based user interface to solve complex systems. The modelling processes include establishing the material body of the physical problem, generating meshes, choosing appropriate boundary conditions, and, finally, running the simulation and examining results. The advantage of this Multiphysics simulation software is the ability to collect many physical effects together to improve the applicability of the results in the real world.

COMSOL Multiphysics was thus in this study used for a 3D simulation of the interactions between the electromagnetic wave and the biological tissue of the human head. The propagation of the electromagnetic wave is given as

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

(1)

where $\varepsilon_r$ is the permittivity of the material, $\varepsilon_0$ is the free space permittivity, $\sigma$ is the conductivity of the material, $\mu_r$ is the permeability of the material, and $\omega$ is the angular frequency.

The COMSOL model of the resulting microwave heating inside the biological tissue is defined by the following equation

$$\rho C_p \mathbf{u} \nabla dT + \nabla \cdot \mathbf{q} = Q + Q_{bio}$$

(2)

where

$$\mathbf{q} = -k \nabla dT$$

and

$$Q_{bio} = \rho b C_{p,b} \omega_b (T_b - dT) + Q_{met}$$

Equation (2) parameters can be defined as follows: $\rho$ is the material density (human head), $C_p$ is the heat capacity at constant pressure, $k$ is the material thermal conductivity, $\mathbf{u}$ is the spatial displacement vector, $T$ is the temperature, $Q$ is the heat source, $Q_{met}$ is the metabolic head source, and $\omega_b$ is the blood perfusion rate. The material properties been used in the simulation are illustrated in Table I; these were taken from [14] and [15].

| Material property          | Value         |
|----------------------------|---------------|
| Microstrip dielectric      | 5.32          |
| Air permittivity           | 1             |
| Head permittivity          | 38            |
| Head conductivity          | 1 S/m         |
| Head thermal conductivity  | 0.5 W/(m.K)   |
| Head density               | 1050 kg/m³    |
| $C_p$ of the head          | 3700 J/(kg.K) |
4. Results and discussion

| Property                  | Value       |
|---------------------------|-------------|
| $C_p$ of the blood        | 3639 J/(kg.K) |
| Blood density             | 1000 kg/m³  |
Figure 2. Distribution of electric field in human head for different levels of the transmitted power: (a) 600 mW, (b) 1 watt, and (c) 1.5 watt.
Figure 3. Distribution of temperature in human head for different levels of the transmitted power after 60 minutes. (a) 600 mW, (b) 1 watt, and (c) 1.5 watt.

![Figure 3](image-url)

Figure 4. Temperature against time in the human head for different levels of the transmitted power.

![Figure 4](image-url)

The model of the human head was adopted from [8] together with the PIFA model seen in [9]. The simulation was performed for three levels of the transmitted power; 600 mW, 1 W, and 1.5 W to find the effect of increasing the transmitted power on head tissue. The distribution of electric field and the temperature were thus obtained for the three levels of transmitted power. Fig. 2 shows the electric field distribution in the head for the three values of the transmitted power (0.6, 1, and 1.5 Watt). As shown in the figure, the electric field increases with rise of the transmitted power where the maximum electric field is equal to 150 V/m when the transmitted power is 600mW; this increases to 200 V/m in the case of 1.5 W transmitted power. The distribution of temperature within the head tissue after 60 minutes is illustrated in Fig. 3 for the three levels of the power of the antenna, and the simulated results of head temperature over time are depicted in Fig. 4 for the same three levels of power. As seen in Fig. 4, the maximum temperature of the human head tissue reaches 41, 44, and 47 ºC after 60 minutes when the antenna transmits power at 0.6, 1, and 1.5 W, respectively. The main difference from previous research is that the antenna used in the model is a practical antenna with dimensions based on commercial mobile phones [15].

5. Conclusion
In this paper, a new study of the interactions between the transmitted power of a mobile antenna and human brain tissue was presented. The distribution of the electric field intensity and the temperature were simulated for different levels of the power; the increase in the temperature in brain tissue over time was also found. From this research, a low level of the transmitted power (0.6 W) appears to have no
effect on brain tissue in terms of temperature, which remains in the range of human body temperature as per British standard 50413 [2].

6. References

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