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A COMPUTATIONAL STUDY OF 2.4 AND 3.7 GHZ RADIATIONS DEPOSITION INSIDE MODELS MADE OF HUMAN TISSUES PLACED NEARBY A MICROSTRIP ANTENNA

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Abstract: *The interest for GHz frequency range in present wireless communication devices is high. Therefore, a continuous need to observe peculiarities of electromagnetic power deposition in human tissues, when they are exposed to signals in this range, is obvious. In this paper, by using an electromagnetic field simulation software, we aimed to highlight the differences between specific absorption rates (SAR) of energy absorption and their geometric distribution in four cases: at two different frequencies and in two tissue models (plane and anthropomorphic). First step was to design and analyse the electromagnetic field provided by a microstrip antenna, and second step was to compute SAR averaged over 10 g of tissue in two models: a three-layered planar model of human tissues and a homogeneous human head. Similarities and differences are discussed, together with observations regarding temperature increase due to exposures and its trend in different layers of tissues.*

Keywords: ultra-high frequency, microstrip antenna, specific absorption rate, electromagnetic field, human tissue model

1. Introduction and Objectives

Using computational electromagnetics for a primary assessment of differences between power deposition in biological structures exposed to radiation emitted by various antennas is very beneficial. A lot of radiofrequency (RF) antenna sources are accounted for inside wireless communications devices used by people in their everyday lives. A wide spectrum of frequencies is available, with a trend of increasing the interest in the GHz – tens of GHz range.

The frequency band centred on 2.4 GHz is widely used by: wireless local area networking of devices (Wi-Fi) in the IEEE 802.11 standards; wireless data networks using ZigBee / IEEE 802.15.4 standard; Bluetooth devices; microwave ovens; radio control toys; radar garage opening systems; some radars; smart power meters; wireless power transmission; internal movement sensors; car alarm; baby monitors; wireless microphones; etc. During Wi-Fi in-use of the mobile phone, its respective antenna may be situated very close to the body or even to the head, which pose special interest for assessing the absorbed power.

Frequencies in the range 3.3-4.2 GHz are presently used as the basis for the first implementations of the fifth generation - 5G of mobile communication, while for example 3.3-3.8 GHz band (3GPP BAND 78) is being tested in Romania also.

In this regard, and based on the general knowledge and similar approaches in the

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recent literature [1]-[5], current approach is devoted to the analysis of two human tissue models exposed to continuous waves at 2.4 GHz and 3.7 GHz. The signals are emitted by a microstrip antenna in all considered cases. The finality of the analysis is the computation of the specific absorption rate (SAR) of electromagnetic energy deposition in biological targets and of the temperature increase due to the caloric transformation of the absorbed power during exposure.

2. Materials and Method

A microstrip antenna (Figure 1a) was modelled using a calculator [6] and the waves propagation was simulated in CST Studio Suite - Electromagnetic Field Simulation Software [7]. The software computes the solutions of Maxwell equations in the mesh using the Finite Integration Techniques. The geometry and dimensions of the antenna were slightly different at the two frequencies: 38 mm width x 29 mm length at 2.4GHz and 24.6 mm width x 19 mm length at 3.7 GHz. Figure 1a shows the microstrip antenna design for 2.4 GHz simulation. In all cases the amplitude of the input signal was 25dBm. The dielectric substrate of the antenna was 1.5 mm thick and had a dielectric constant ε_r=4.4 at both frequencies. Antenna radiation impinges human tissue models.

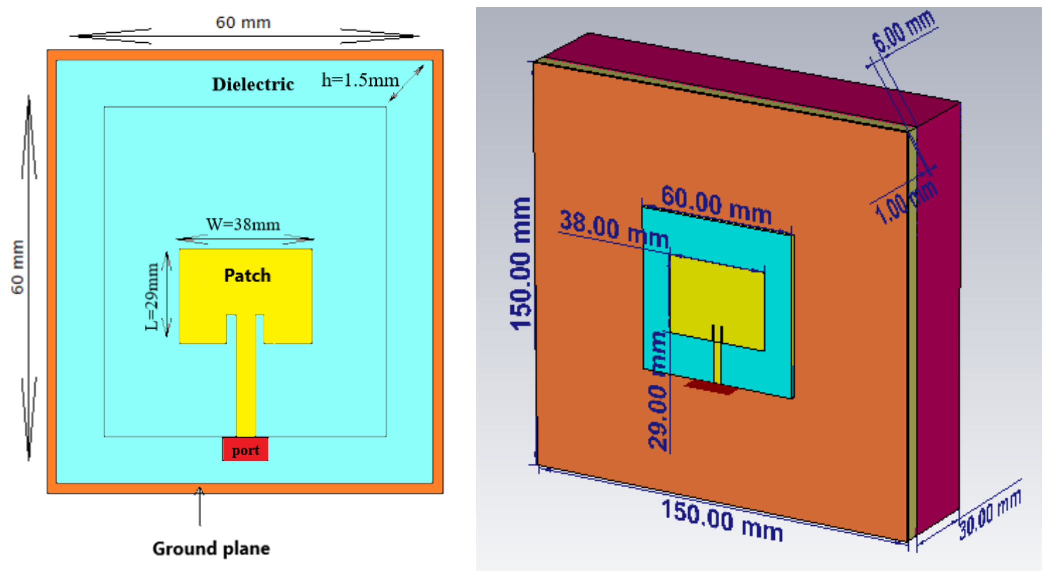

Figure 1: a. Microstrip antenna geometry; b. Multilayer model of three human tissues (skin, fat and muscle) with antenna positioned to emit radiation at 2.4 GHz

Two biological models were used to simulate waves propagation with the aim of observing the power deposition inside them: a) a planar multilayer model made of human skin, fat and muscle (Figure 1b); it is mimicking a portion of the chest while a user may wear the emitting device in a pocket; the dielectric parameters of the tissues at the two frequencies were extracted from [8]; b) a homogeneous model of human head; it is mimicking the use of a mobile phone in “cheek position” while talking; the dielectric parameters of the head model were: electric conductivity:1.37 S/m at 2.4 GHz; 2.07 S/m at 3.7 GHz; relative permittivity: 33.64 at 2.4 GHz and 32.37 at 3.7 GHz.

The antenna was always positioned relative to the tissue model so as the direction of maximum radiation to be perpendicular to the model surface. In the case of the multilayer model, the distance between antenna and model surface was 3 mm while in the case of head model antenna was placed in contact with its surface.

3. Results and Discussion

The initial analysis was made on the antenna radiation pattern at the two frequencies (Figure 2). The maximum gain is 1.62 dB higher for the microstrip antenna at 3.7 GHz than at 2.4 GHz. The main lobe, as expected, is very similar at both frequencies even though the geometry of the antenna is not exactly the same. However, at 3.7 GHz the half power beam-width is larger by 15 degrees than at 2.4 GHz.

Following the specifications in the ICNIRP Guidelines [9] SAR averaged over 10 g of tissue was computed and graphically represented in the irradiated models.

Figure 3 shows the averaged SAR distribution in the planar multilayer model at both frequencies. It is observed that “hot spots” of SAR have different positions on the model at the two frequencies, and, as expected, at 3.7 GHz the maximum average SAR is larger than at 2.4 GHz (1.78 times).

Using an energetic relation between SAR and temperature variation ΔT, one can determine the temperature increase in function of the duration of exposure dt in each tissue of the multilayer model, when we know the specific heat of the tissue, c (Figure 4).

$$\Delta T = \frac{SAR * dt}{c}$$

It is shown that during 3 hours (10800 s) of irradiation, the temperature increase in the tissues composing the model suffers a slight different behaviour at the two frequencies.

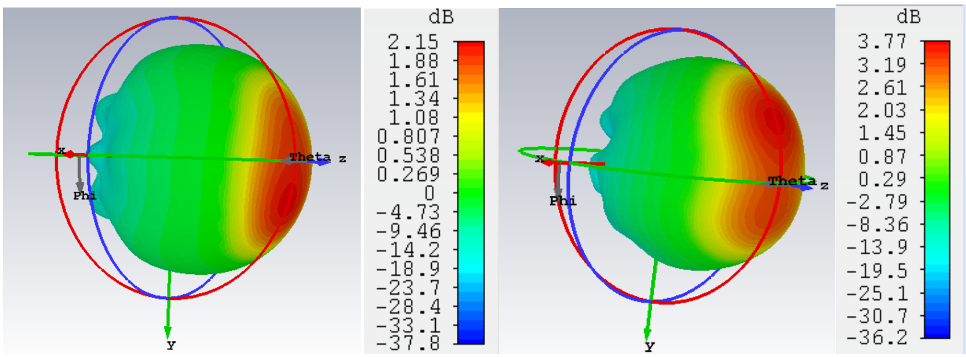

Figure 2: Radiation pattern of the microstrip antenna at: a. 2.4 GHz; b. 3.7 GHz

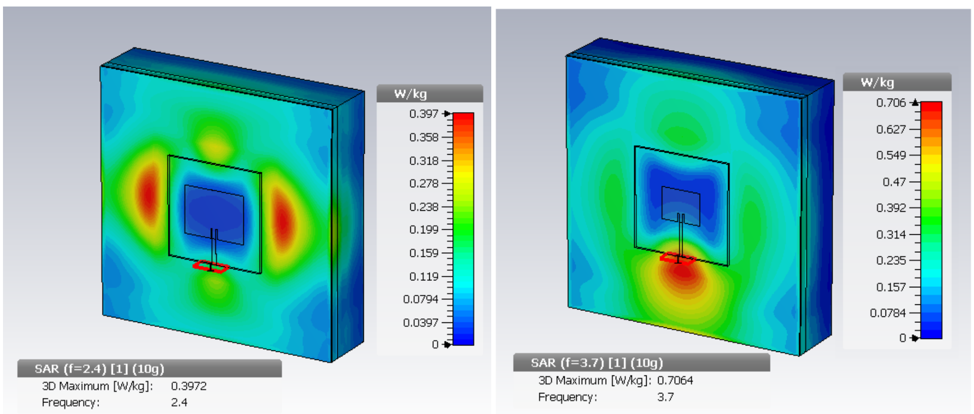

Figure 3: SAR (averaged over 10 g of tissue) distribution in the multilayer model of skin-fat-muscle sandwich at: a. 2.4 GHz; b. 3.7 GHz

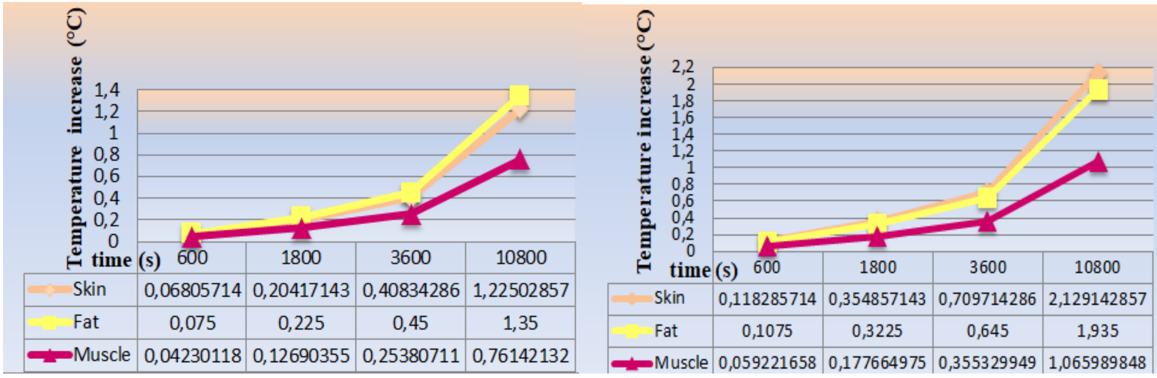

Figure 4: Temperature increase due to exposure over time in the multilayer model of tissues: a. 2.4 GHz; b. 3.7 GHz

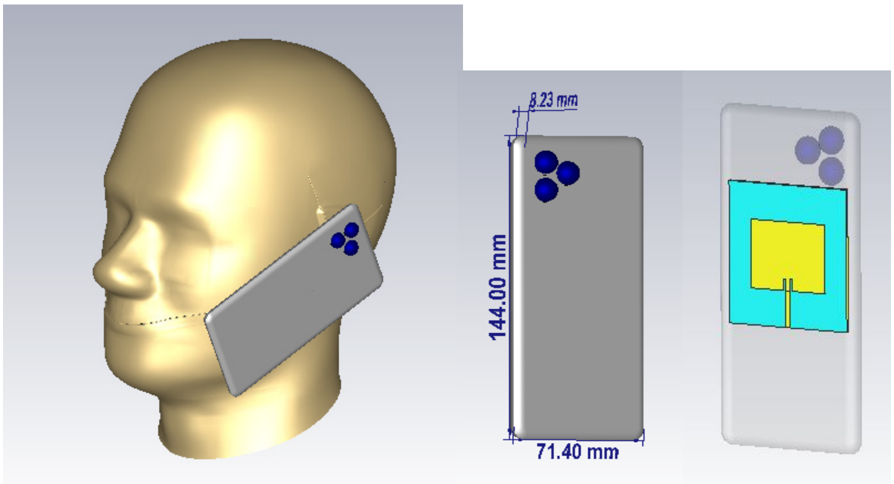

Figure 5: Model of the head filled with homogeneous material mimicking average head dielectric properties, model of the phone and positioning of the antenna in relation to the phone and cheek

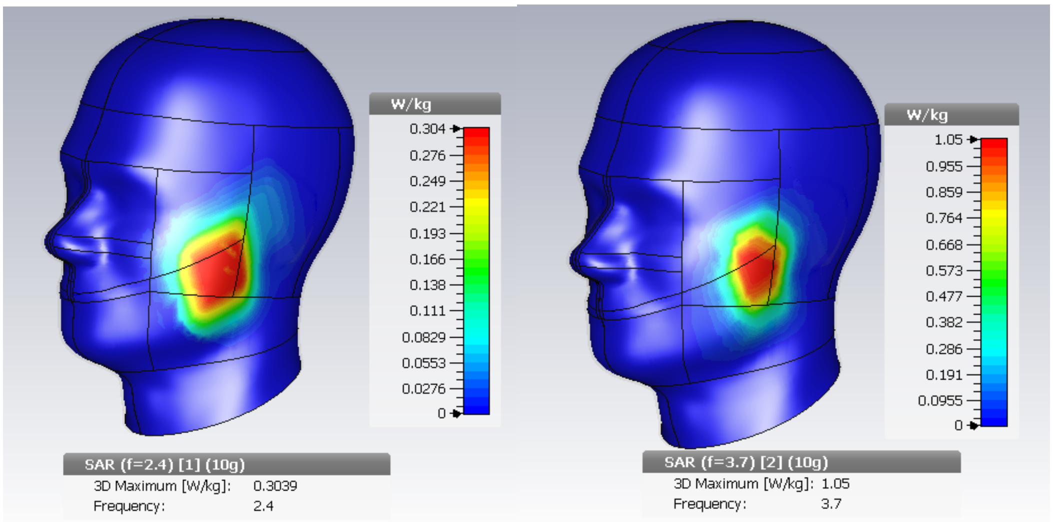

Figure 6: SAR (averaged over 10 g of tissue) distribution in the homogeneous human model – at cheek surface, when exposed to radiation of microstrip antenna at: a. 2.4 GHz; b. 3.7 GHz

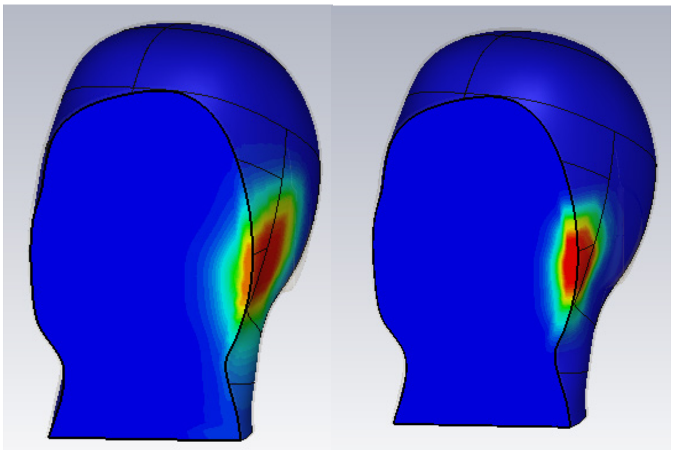

Figure 7: SAR (averaged over 10 g of tissue) distribution in the homogeneous human model – in cheek depth, when exposed to radiation of microstrip antenna at: a. 2.4 GHz; b. 3.7 GHz

However, the rate of temperature increase is very low in both cases, not posing hazard problems during a usage period of the antenna emission of the order of tens of minutes. Practically, 1 degree C heating – which is a threshold limit [9], is obtained for longer than 1 hour emission. What is interesting to note is the different slope of the heating curves in the skin and fat at the two frequencies, fact that underlines the significance of tissue dielectric properties in relation to the frequency / energy of the signal.

Figure 5 shows the second model – the homogeneous head and the position of the phone model and the microstrip antenna.

Figure 6 depicts SAR distribution over the cheek (at surface) while Figure 7 depicts the depth in the model at which the SAR is distributed. Also in these figures SAR was computed as average over 10 g of tissue. Differences are obvious at the two frequencies, and with this occasion it is also observed how important is the geometry of the irradiated object. The maximum average SAR is 3 times higher at 3.7 GHz than at 2.4 GHz, the power distribution is more localized and the penetration in the model is much more dependent also on the antenna radiation pattern. Such observations prove the multi-variable dependence of SAR.

4. Conclusions

A radiating antenna will differently impact a biological model exposed to its radiation due to its frequency-specific radiation pattern. Starting from this first difference on, other ones will gradually add due to differences in geometry of the targeted model, its dielectric properties, and the configuration of the exposure set-up.

Present simulations followed particular situations of human tissues exposure and highlighted suitability of computational electromagnetics to provide solutions for targeted experiments.

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