Evaluation of SAR induced by a Planar Inverted-F Antenna based on a Realistic Human Model

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Abstract— **In this paper the absorption by the human body of electromagnetic (EM) radiation generated by a Planar Inverted-F Antenna (PIFA) from a modern mobile phone is investigated through the evaluation of the Specific Absorption Rate (SAR) in head, brain and hand regions using Sim4Life (S4L) and a realistic anatomical model. Several scenarios were evaluated, by varying the distance between the antenna and the head, the feeder position and the orientation of the antenna. The effect of the presence of the hand was also studied and, finally, different communication bands were considered. The main results show that the presence of the hand is determinant to reduce SAR on head and brain, while bottom orientations of the antenna reduce the SAR on the brain, but increase the SAR in other tissues.**

Keywords— **Electromagnetic fields, PIFA, Radio-frequency, SAR, Sim4life.**

I. Introduction

Nowadays electromagnetic (EM) fields exposure is present in numerous everyday situations. User acceptance of the new technologies has been widespread, therefore the number of users is large and is growing. In 2011, the World Health Organisation (WHO) and International Agency for Research on Cancer (IARC) issued a press release classifying radio-frequency EM fields as possibly carcinogenic to humans, based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use [1].

Several studies have been previously performed on the evaluation of SAR induced by mobile phones using EM simulation. However, the outcome of SAR evaluation by simulation is dependent on the structural accuracy and resolution of the model, as well as other factors, such as antenna type, antenna radiation frequency and efficiency, antenna inclination with the head and distance of antenna from head [2]. The work reported in [3] considered a PIFA, a miniaturised antenna commonly used in modern mobile phones, operating near a human head and hand models based on geometric spherical or cubic shapes composed by layers that mimic the tissues in the head. Other works [4, 5] also considered a PIFA together with a CAD EM phantom, named SAM head that is composed of a shell of 2 mm filled with homogeneous liquid to represent head tissues. However, to the best of the authors knowledge, there are no reports of SAR evaluation using more realistic human models, which would be certainly relevant in order to further understand how EM exposure affects the different human tissues.

This paper expands on the previous work by evaluating local and spatial average SAR induced by a PIFA on an anatomical high-resolution realistic human model, which allows for a detailed analysis of the radiation absorption in every tissue or organ of the body, as well as mimicking particular hand-head configurations of realistic uses of a mobile phone. Additionally, this work also considers other frequency bands (FB) beyond those commonly used in papers that treat the subject (900 MHz and 1800 MHz) by also considering typical UMTS and LTE communication bands with frequencies of 2100 MHz and 2600 MHz, respectively. The paper addresses the evaluation of SAR in the head, brain and hand regions by analysing the impact of changing different variables, namely the distance between antenna and head, the presence of the hand holding the handset, the antenna feeder position, tilt positions and frequency of operation.

This paper is organised as follows: Section II presents the considered models of the human body and PIFA as well as the used method. Section III presents the obtained results and finally conclusions are given in section IV.

II. MODELS AND METHODS

In this section we describe the methods employed for evaluating the SAR within the human model, as well as the characteristics of the models considered.

Simulation platform: The chosen simulation platform was Sim4life (S4L), which is a computational life sciences platform that uses the Finite Time Domain (FDTD) method as an EM field solver. FDTD is the most widely accepted computational method for SAR evaluation.

Human Model: The employed virtual population model [6] was Duke, which consists in an anatomically realistic 3D model of a 34 years old adult male. Similarly to real biological tissues, the tissues of the realistic phantom have different electrical properties according to frequency. The antenna was placed close to the ear as shown in figure 1 and it does not touch the head or the hand of Duke.

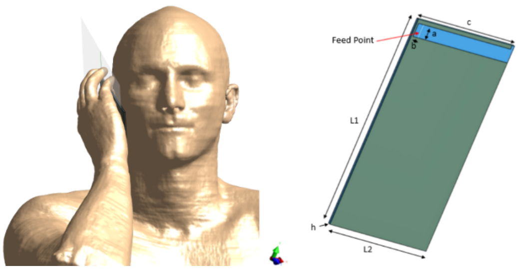

Fig. 1: Duke and PIFA model. 900 MHz PIFA ($L_1 = 109.6, L_2 = 58.5, h = 1.6, a = 7, b = 3.05, c = 58$).

Antenna Model: A planar inverted-F antenna was designed according to the dimensions of modern mobile phones (Fig. 1) and optimised in a 3D EM simulator. The model of the antenna is based on FR4 substrate. Taking into account the different typical FB that are used nowadays, four PIFAs were designed, corresponding to the various generations of mobile systems, 2G/GSM - 900 and 1800 MHz, 3G/UMTS - 2100 MHz and 4G/LTE - 2600 MHz.

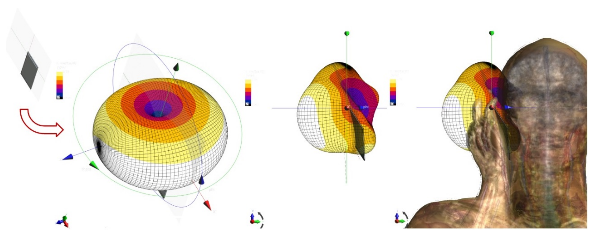

Fig. 2: Simulated far field radiation pattern from PIFA model on free space (left) and with Duke (middle/right).

In figure 2 the far-field (FF) radiation pattern of the antenna is shown, simulated on free space, where it is almost omnidirectional, and then simulated with the human model present, which creates a visible distortion in the radiation pattern. This distortion is expected since the high permittivity of the human tissues absorb the radiation, therefore precluding radiation from reaching the far-field in that direction.

Energy absorption metric: The specific absorption rate (SAR) is the considered metric, which, according to International Commission on Non-Ionising Radiation Protection [7], represents the rate at which energy is absorbed in body tissues, in watt per kilogram (W/kg).

For harmonic excitation and after steady state has been reached, the local SAR is given by the expression $SAR = \frac{\sigma_E}{2\rho}|E^2|$ where σ_E (S/m) is the tissue electric conductivity, ρ (kg/m^3) is the mass density of tissue and E (V/m) is the amplitude of the generated internal electric field. However, the local SAR is not always useful, because it is too sensitive to approximations in the computational methods. An averaged form of SAR over the region mass (M) is the one mostly found in the literature:

$$\langle SAR \rangle_M = \frac{1}{M} \int_{R(M)} SAR(r) dm$$

For estimating the values of SAR in 10 g of tissue, a quantity named Peak Spatial Average SAR (psSAR) based on previous equation was considered, which is defined by an IEEE and International Electrotechnical Commission (IEC) standard. The SAR values averaged over 10 g biological tissue were evaluated adopting the European standard algorithm, which established a limit of 2 W/kg.

III. RESULTS

The baseline model consists of Duke holding the PIFA by the hand (Fig. 1). The antenna is in cheek position, with the feed point close to the ear and working at 900 MHz with 600 mW of input power. A slice view of the electric field distribution and respective SAR can be seen in figure 3. Head and hand skin were the tissues with the highest absorption (Local SAR of 21.3 and 25 W/kg, respectively). In brain, the grey matter had the highest absorption (Local SAR of 1.41 W/kg). The standard limit was exceeded in head and hand.

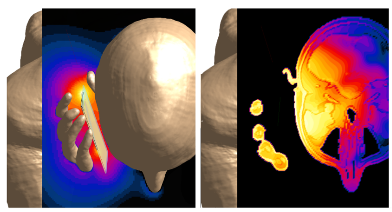

Fig. 3: Horizontal slice of the Electric field (left) and SAR (right).

A. Distance

The PIFA was moved away from the head, from 2 to 10 mm in steps of 2 mm. The results confirm that SAR decreases as the distance increases, as expected and reported in literature using other type of antennas [8, 9, 5]. This decrease was circa 25% for each 2 mm of distance in local SAR. Beyond the default distance of the baseline model, the standard limit was not exceeded in any of the other distances tested. The Peak Spatial-Average SAR in 10g of tissue limit of 2 W/kg was exceeded at the default distance (0 mm) in the head tissues (figure 4), but not on the brain tissues.

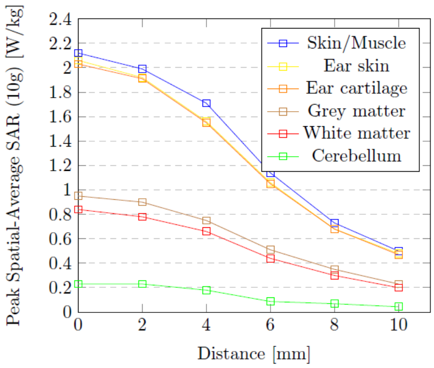

Fig. 4: psSAR-10g in head and brain tissues as a function of distance.

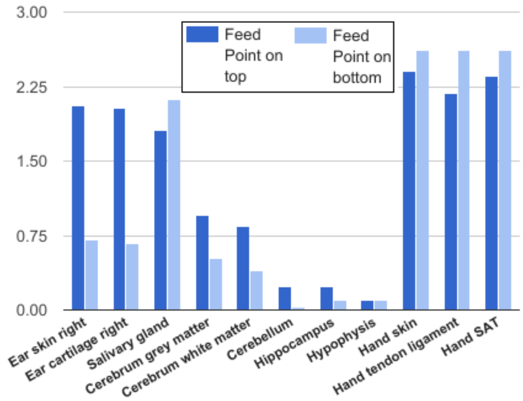

Fig. 5: psSAR-10g as a function of feeder position.

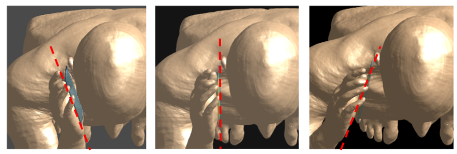

Fig. 6: Cheek (left) and Tilt positions (middle/right).

B. Hand

A variation of the baseline model was created with the hand removed to compare the results with the baseline model. With the hand removed the local SAR values were circa 17.5% higher in head tissues and circa 20.6% higher in brain tissues compared to when the hand was present, which shows that the presence of the hand is important to reduce SAR in head and brain. This can be explained by the fact that the high permittivity hand tissues absorb some of the power radiated by the antenna (Okoniewski & Stuchly, 1996 cit. by [10]).

C. Feed point position

Another variation of the baseline model was created with the antenna rotated 180 degrees in order to compare it with the baseline position. In this position the feed point is closer to the cheek, while in the baseline position the feed point is closer to the ear. The rotated orientations of the PIFA, i.e., with feed point rotated 180 degrees to the bottom, significantly reduce the SAR on the brain, while slightly increasing it in other tissues, mainly in the hand. The decrease of local SAR was circa 85.7% in ear region tissues, 28.9% in cheek region tissues and 59.7% in brain tissues (Fig. 5). This is explained by the fact that higher values of electric field occur close to the feed point. This is in agreement with a similar study [8], which concluded that higher SAR is expected in tissues closer to the feed point of the antenna.

D. Tilt position

Two different tilt positions were evaluated and compared with the baseline position (cheek), as shown in figure 6. The results showed a decrease in SAR values when a tilted position was used of circa 44.6% in head tissues and 48% in brain tissues. For the evaluated tilt positions, the standard limit was not exceeded (Fig. 7). It can be concluded that tilt positions are preferable than cheek positions in terms of SAR. The same conclusions were achieved by an experimental intercomparison study [11] performed in 17 laboratories to test the errors between SAR measurements. Hossain et.al. [5] also concluded that antenna tilt positions produce relatively low SAR in most cases, although with some exceptions.

E. Frequency band

Four FB were considered with associated typical input power values. The FB considered were GSM900, GSM1800, UMTS and LTE, with input powers of 600 mW, 125 mW, 125 mW and 199 mW, respectively. As shown in figure 8, the results show that head and brain tissues have lower psSAR at UMTS and GSM1800 and higher psSAR at GSM900, which clearly demonstrates that the SAR is mainly determined by the input power and not by the frequency of operation. The standard limit of 2 W/kg was only exceeded at GSM900. Additionally, if one compares the results obtained at the frequencies of 1800 and 2100 MHz, both at the same power, it is noticeable some increases in certain tissues, which shows that, while marginally, SAR also increases with frequency.

IV. CONCLUSION

Using an anatomical high-resolution realistic human model we were able to evaluate local and spatial average SAR

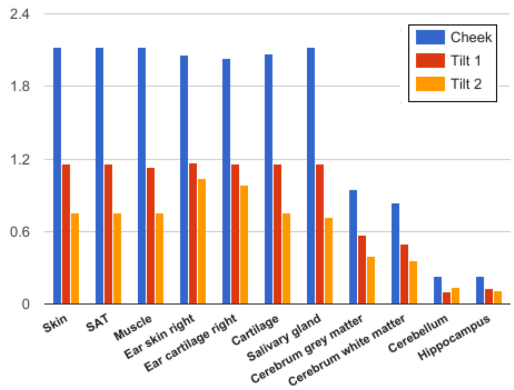

Fig. 7: psSAR-10g in head and brain tissues as a function of tilted positions.

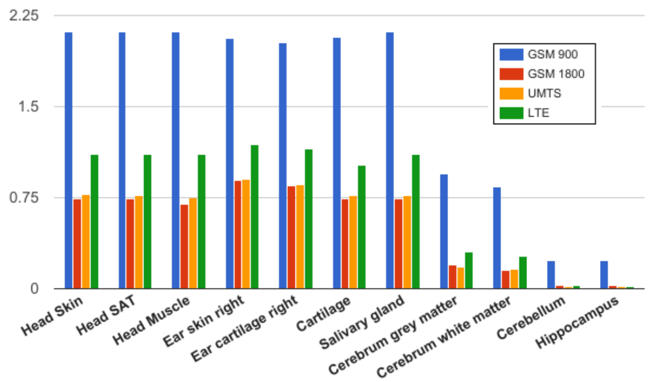

Fig. 8: psSAR-10g in head and brain tissues as a function of frequency band.

induced by a PIFA in every tissue of the head, and to mimic particular hand-head configurations of realistic uses of a mobile phone. It was concluded that the limit of 2 W/kg was slightly exceeded at the default distance (0 mm). It was also concluded that the presence of the hand is determinant to reduce the SAR on head and brain tissues, while bottom orientations of the antenna reduce the SAR on the brain, but increase the SAR in other tissues, mainly in hand. The analysis of the FB showed that head and brain tissues have lower SAR at UMTS and GSM1800 and higher SAR at GSM900, which clearly demonstrates that the SAR is mainly determined by the input power and not by the frequency of operation. Future work consists in embedding the antenna in the usual mobile phone materials and to investigate the effect of materials that could be used as shield to reduce SAR.

Conflict of Interest

The authors declare that they have no conflict of interest.

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