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A STUDY OF THE EFFECTS OF METALLIC PINS ON SAR USING A SPECIFIC ANTHROPOMORPHIC MANNEQUIN (SAM) HEAD PHANTOM

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Abstract

This paper presents the effects of facial metallic pins on the Specific Absorption Rate (SAR) in the head, when radiated by a microwave source placed in front of the face. A Specific Anthropomorphic Mannequin (SAM) is adapted for use with a DASY4 and a digitised SAM head is modelled using in-house Finite-Difference Time-Domain (FDTD) code, enabling comparisons between measurements and simulations. A continuous wave (CW) half-wave dipole is placed in front of the face, representing a communications enabled personal data assistant mobile communications equipment (PDAMCE). Parametric studies have shown that metallic pins that are roughly half a wavelength long placed along the eyebrow, increase the 1g and 10g SARs at 900MHz by around five fold. A greater than five fold increase is seen at 1800MHz. Measurements show very good agreement with simulations.

1 Introduction

The interaction of energy from mobile phones into the head is a topical area of research. In order to allow meaningful comparisons to be made between different types of devices, a set of international standards have evolved that suggest maximum levels of radio frequency energy into humans and experimental techniques for modelling and measurement. A typical example is that of the IEEE head phantom that is commonly used to benchmark levels of energy delivered by mobile phones to the ear of a representative phantom [1].

Recently, Personal Data Assistants (PDAs) have begun to incorporate communications modules. With this new connectivity and their inherent large screens, mobile internet browsing is rapidly becoming a new trend among PDA users. This, along with the use of 3G video calls, has tended toward a device held in front of the face rather than to the ear. Studies in the past by the authors of this paper have shown that metallic spectacles of certain dimensions can increase the SAR in the eyes [2][3] when the face is illuminated by radio frequency energy from the front. Other FDTD studies have

also examined the SAR in the eyes when radiated from in front of the face [4]–[6]. Measurements were carried out by Balzano [7] and Cleveland [8] using human skulls filled with brain simulating materials. While there are many FDTD based studies, measurements from in front of the face using the recently introduced IEEE SAM head phantom standard [1] are less common. The twin head phantom used in the standard DASY4 system [9] is designed specifically for side-of-head SAR measurements and so does not lend itself to front of face measurements [10]. The authors have recently modified a SAM head for SAR measurements behind the face, which can be used with a standard DASY4 kit. The suitability of the modified SAM head (which will be referred to as the Loughborough SAM head) for accurately measuring the SAR in the facial area has been verified through simulation [10] and experimentation [11].

With a standardised measurement system for in front of the face radiation sources now tested and verified, the effects of metallic jewellery on SAR can be reliably measured. In this paper, we present the effects on SAR of metallic pins placed in front of the face when radiated by 900MHz and 1800MHz dipole sources. The metal pins could represent the horizontal crossbars of half-rimmed spectacles worn by many people today, an example of which is shown in Figure 1. The 3D graphic illustrates how a metal pin could be positioned to represent the crossbar of the shown glasses. Other sources of metal on the face could be from clip-on sunglasses worn over prescription glasses, rings, studs and piercings [12].

Figure 1 - Example of a half-rimmed spectacle and how it would be depicted in a simulation

2 Description of Model

An in-house 3D FDTD code [2][3] has been written and verified against commercial software, and is used in this study. Perfectly Matched Layers (PML), with geometric grading [13], absorbing boundary conditions are used to terminate the grid. The PML is eight cells thick and is positioned at least twelve cells from the head. The Yee cell size used for simulations in Section 3 is 2mm. This allowed the parametric studies to be conducted quickly. At this resolution, the lowest number of cells per wavelength was always greater than ten at 1800MHz, and reasonable results have been obtained with only four [5][14]. The time step was 3.336pS. The simulations were run for at least ten cycles and until stability was achieved (at least 1660 time steps at 1800MHz). The simulations in Section 4 use 1mm Yee cells because following the contours of the face required a higher resolution. The geometry of the problem space is as follows; the X axis runs from the tip of the nose to the back of the head, the Y axis is from ear to ear and the Z axis runs from chin to top of the head. The axis are shown in Figure 1 and 3.

SAR is the standard criteria to measure the amount of electromagnetic energy absorbed in the body and is calculated as in equation (1)

$$SAR = \frac{\sigma |E|^2}{\rho} \quad (\text{W/kg}) \quad (1)$$

Where $|E|$ is the RMS magnitude of the electric field strength vector, ρ is the mass density of the material in kg/m^3 and σ is the electrical conductivity in S/m. The SAR is calculated in FDTD with the twelve-field approach as used by Caputa [15].

2.1 Dipole model

To allow accurate comparison between simulations and measurements, a dipole model [16] has been used as the excitation source in this study. The dipole is horizontally orientated along the Y axis (from ear to ear) and fed at its centre with a sinusoidal CW source. In the FDTD simulations, the 900MHz dipole is 162mm long and the 1800MHz dipole is 74mm long. The dipoles were modelled by setting the tangential E-field components to zero along the length of the dipoles. Both simulation and measurement results were normalised to 1W transmitted power.

2.2 The phantom head model

The head model in this paper is based on the IEEE SAM head phantom [1]. The rear of the head has been removed to allow E-field probe of the DASY4 to access the inside of the face region. In the FDTD model, the original complete SAM head is discretised with a resolution of 2mm. Previous studies have shown that there is very little difference in SAR values between the complete SAM head and the truncated Loughborough SAM head. In the experimental setup, the phantom is fixed face down and filled with brain simulating

liquid. The properties of the brain simulating liquid for both simulation and measurement at 900MHz are $\sigma=0.96\text{S/m}$, $\epsilon_r=41.28$, $\rho=1000\text{kg/m}^3$ and at 1800MHz are $\sigma=1.37\text{S/m}$, $\epsilon_r=40.48$, $\rho=1000\text{kg/m}^3$. The properties of the shell are $\sigma=0\text{S/m}$, $\epsilon_r=3.5$, thickness = 2mm in most areas except for at the joining seam and pinna. The Loughborough SAM head is shown incorporated into the DASY4 in Figure 2.

Figure 2 - Modified SAM head integrated into DASY4

At the join between the two halves of the head, there is a 17mm wide seam. This has been reduced in the facial area to a seam that is 10mm wide and 3mm thick. We have previously shown that this reduced seam has negligible effects on the measured SAR [11].

2.3 Modelling and geometry of metallic pins

The location of the metallic pin and dipole relative to the SAM head phantom are shown in Figure 3.

Figure 3 - Location of pin and dipole relative to the SAM head

The pin was modelled in FDTD using metallic Yee cells, by setting the conductivity of the cells equal to the conductivity of copper [2]. This technique has been used by both Nikita [17] and Bernardi [18] in the past to model metallic shapes. The pins studied here are 2mm thick (2 Yee cells). Both pin and dipole are aligned along the Y axis and are in the same XY plane. The eyebrow XY plane is defined as being 54mm up from the tip of the nose in the Z direction. The dipole centre is located 104mm from the phantom surface and is fixed for all simulations and measurements. The distance D, which is the separation between the pin and the phantom surface, is a variable and is the subject of further study in the proceeding section.

3 Simulating Optimum Sizes and Locations for the Pins

Using FDTD simulations initially, parametric studies were conducted to find the optimum pin length and location for causing maximum SAR in the head at both 900MHz and 1800MHz. In Section 4, the optimum sizes and locations will then be incorporated into the DASY4 to verify the simulated worst-case scenarios. Figure 4 shows the change in 1g SAR as the pin length is increased at 1800MHz. These results are at a fixed distance of 8mm from the surface (measured from the outside surface of the pin to the outside surface of the SAM phantom). The dipole source is located as shown in Figure 3 and is 74mm long. A sharp increase in the 1g SAR from 0.63W/kg to 4.95W/kg is noticed when a 70mm long pin (corresponding to 0.42λ) is placed in front of the eyebrows. Pins shorter than 30mm (0.18λ) and pins longer than 85mm (0.51λ) only increase the 1g SAR by a very small percentage.

Figure 4 - 1g SAR at 1800MHz with increasing pin length (pin is 8mm from the phantom surface)

Using the resonant length of 70mm, the location of the pin (distance D in Figure 3) is then varied in a similar FDTD parametric study. The change in 1g SAR with increasing pin distance is shown in Figure 5. For this particular length (70mm), the optimum location for the pin is 8mm from the surface of the SAM phantom

Figure 5 - 1g SAR at 1800MHz with increasing 70mm pin distance from the phantom surface

A similar study for the 10g SAR change with pin size and location showed that the optimum pin size was 70mm and the optimum location was 10mm from the SAM surface. The study was also repeated at 900MHz. The dipole length was changed to 162mm but the distance to the phantom remained unchanged. As the separation distance of 8mm gives the biggest increase in SAR at 1800MHz and it is a realistic location for the crossbar of a semi-rimmed spectacle, the 900MHz pin length study also used the same distance. With the location of the pin fixed at 8mm from the surface, the parametric study changed the length of the pin, observing the effect on the 1g and 10g SAR. The 1g SAR values are shown in Figure 6. A sharp increase in the 1g SAR from 0.40W/kg to 2.56W/kg is observed when the pin is 150mm long, which corresponds to 0.45λ . Pins shorter than $\sim 0.27\lambda$ have negligible effect on the SAR.

Figure 6 - 1g SAR at 900MHz with increasing pin length (pin is 8mm from the phantom surface)

With the pin length fixed at 150mm, the variation of 1g SAR was studied at 900MHz with increasing pin/phantom separation distance D. The simulated results are presented in Figure 7.

Figure 7 - 1g SAR at 900MHz with increasing 150mm pin distance from the phantom surface

At 900MHz, the optimum position for the 150mm pin is 20mm from the surface. The graph shows a more gradual increase in 1g SAR with increasing separation distance compared to the 70mm pin at 1800MHz. Unlike previously, there is an obvious increase in the 1g SAR when the pin is touching the phantom surface. This is most likely due to the size and shape of the Loughborough SAM head. The 150mm pin length is comparable to the width of the phantom where as at 1800MHz, the 70mm pin was less than half the size. In the FDTD model, the central 42mm of the eyebrow section is flat and so the 70mm pin is touching the phantom surface for most of its length. Previous work by the authors [19] using a cubic phantom with varying pin sizes and locations showed that at 1800MHz, all pin sizes touching the surface of the cubic phantom had negligible effect on the 1g and 10g SAR. However, in the 900MHz scenario, as the temples of the head curve away from the face towards the ears, the 150mm pin only touches the phantom at a relatively small section of its full length. This is most likely to be the reason why the 1g SAR in Figure 7 is increased at zero separation distance.

4 Experimental Results

In order to verify the simulated maximum SAR caused by the resonant pins, SAR measurements were carried out using the Loughborough SAM head incorporated into the DASY4. The optimum pin size for 1800MHz was 70mm and at 900MHz, the optimum pin length was 150mm. Although not impossible, the optimum separation distance of 20mm for the pin at 900MHz was though to be less realistic regarding the spectacles scenario compared to the optimal separation distance of 8mm for the pin at 1800MHz. Therefore, SAR measurements at both frequencies were carried out with the pins located 8mm from the phantom surface. Cotton thread was used to hang the pins in the correct locations. A small piece of Styrofoam was wedged between the pin and the phantom to ensure that the robot's movements did not destabilize the pin. It was assumed that the cotton and

Styrofoam have very little effect on the measured SAR. The DASY4 setup at 1800MHz is shown in Figure 8.

Figure 8 - Measurement setup at 1800MHz

Local SAR measurements were taken along the inside of the Loughborough SAM head from ear to ear in the same XY plane as the dipole and pin. During the surface scans, the detectors inside the E-field probe were located 4mm from the inside surface of the phantom. Therefore, in the simulations, the SAR values were also calculated 4mm into the brain simulating liquid. Simulated and measured local SAR scans with and without the pins at 1800MHz and 900MHz are shown in Figure 9 and Figure 10 respectively.

Figure 9 - Local SAR at 1800MHz along the inside surface of the phantom behind the pin

With the inclusion of pins, there is a very obvious increase in the local SAR inside the head directly behind the centre of the pins at both frequencies; more so at 1800MHz. These measured and simulated local SAR values are actually 4mm inside the surface, and so the inner surface local SAR values are naturally even higher.

Figure 10 - Local SAR at 900MHz along the inside surface of the phantom behind the pin

There is very good agreement between measured and simulated results. The dip in the local SAR at the centre of the head without a pin is due to the shape of the eyebrows and eyes. As the eyes sockets curve into the head, the eyebrows protrude forward away from the face. As a result, the eyebrow region is exposed to radiation from a number of different angles. At the centre of the head, it is the nose bridge that curves into the head but this curvature is much less than that of the eye sockets. Therefore, the centre of the head is exposed to slightly less radiation. This results in a lower SAR at the central part of the head compared to the eyebrows either side.

In addition to surface scans, the DASY4 also calculated 1g and 10g SAR with and without pins at both 900MHz and 1800MHz. Simulated and measured results are given in Table 1. The without pin results are in excellent agreement whereas the with pin results show some variations. This could be attributed to inaccuracies in placing the pin during measurements and the 2mm staircasing effect in the FDTD code. At both frequencies, the 1g and 10g SARs increase by more than 5 times when the pins are introduced to the system.

SAR at 900MHz (W/kg) 150mm pin 8mm from surface						
	No pin		With pin		% increase	
	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.
1g	0.39	0.36	2.26	2.76	579	767
10g	0.26	0.25	1.30	1.57	500	628
SAR at 1800MHz (W/kg) 70mm pin 8mm from surface						
	No pin		With pin		% increase	
	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.
1g	0.86	0.86	4.95	5.27	785	613
10g	0.47	0.47	2.42	2.52	550	536

Table 1 - Simulated and measured 1g and 10g SAR values inside the head with and without pin

5 Conclusions

This paper has investigated the effects of placing metallic pins in front of the eyebrows on SAR inside the head, when the head is subject to frontal microwave radiation. Detailed parametric studies in FDTD at 900MHz show that pins between 0.40λ and 0.48λ long increase the SAR inside the head, with peak increase occurring for a 0.45λ (150mm) pin. At 1800MHz, pins that are between 0.36λ and 0.45λ long resonate the most, with the largest effect now occurring when the pin is 0.42λ (70mm) long. Longer and shorter pins only increase the SAR by very small amounts. There also appears to be optimum locations for the pins. At 900MHz, the maximum 1g SAR is produced when the pin is located 20mm ($6/100\lambda$) from the surface of the phantom and at 1800MHz, the optimum distance is 8mm ($\sim 5/100\lambda$). At both frequencies, the introduction of the pins increase the 1g and 10g SAR values by more than 5 fold. These results have been successfully verified through measurements using the Loughborough SAM head phantom and a DASY4.

Future work in this area will involve replicating this study using actual metallic semi-rimmed spectacles and other everyday jewellery. The special case of pin touching the surface of the phantom at different frequencies also requires further study.

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