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Citation: WHITTOW, W.G. ... et al (2006). A study of head worn jewellery, mobile phone RF energy and the effect of differing issue types on rates of absorption. IN: Proceedings of The European Conference on Antennas and Propagation : EuCAP 2006, Nice, France

Additional Information:

- This is a conference paper

Metadata Record: https://dspace.lboro.ac.uk/2134/2953

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A STUDY OF HEAD WORN JEWELLERY, MOBILE PHONE RF ENERGY AND THE EFFECT OF DIFFERING TISSUE TYPES ON RATES OF ABSORPTION


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ABSTRACT

This paper investigates the effects of metallic jewellery on the SAR in progressively more complex models of the human head, using the FDTD method. A half-wavelength dipole excitation at 1800MHz is positioned in front of the head to represent a cellular enabled personal communication device. FDTD results show good agreement with DASY 4 measurements. Metallic jewellery has been found to increase SAR in the head and the levels of SAR depends on the shape and the electrical properties of the tissues in the head. A metallic pin was found to increase the SAR averaged over 1g by 16.0 times in a homogeneous cubic head, whereas, the same pin increased the 1g SAR in an anatomically realistic head by a factor of only 2.5. The results shown in this paper are for a metallic pin that may represent a facial piercing, a section of metallic spectacles or a microphone for a hands free kit.

1. INTRODUCTION

There is concern that the radiation from mobile phones may adversely affect human health. The agreed unit to quantify these effects is Specific Absorption Rate (SAR). In previous works, the authors [1] [2] have found that metallic spectacles can significantly increase the SAR in the eyes and head. It is commonly estimated that there are a billion mobile phone users in the world. Many of these may also wear metallic jewellery or have metallic objects in close proximity to their head. This includes facial piercings, metallic spectacles, jewellery on the hands, hairclips and bluetooth microphones. For clarity metallic objects in this paper are limited to metallic pins.

A rigorous Finite-Difference Time-Domain (FDTD) model is used to model a CW source positioned in front of the head. This will replicate a communication enabled PDA used in front of the face. This is topical as such hand held devices held to the front of the head are becoming popular.

In recent years, work has been presented regarding mobile phones positioned near the ear [3] [4]. The head has also been irradiated from in front of the eye using realistic mobile phone models [4].

Recently, Virtanen [5] found that metallic implants inside the head could increase the SAR. He considered metallic loops and pins inside a cylindrical head. Tay [6] has investigated the change in radiation efficiency using a passive reflector and directive element. He found that the efficiency could be increased if a metallic scatterer was positioned near to the dipole. In the same area Cooper [7], modelled a geometric head, and Bernardi [8] investigated an anatomical head, irradiated by simple dipoles positioned near metallic walls. Both found that metallic walls could increase the power absorbed in the head. Similarly Cooper [9] considered metal implants inside the head and found that they increased the SAR in the surrounding region. These papers show that metal objects close to biological matter may increase SAR in that matter. Troulis [10] used the FDTD method to briefly examine thin metallic spectacles on a heterogeneous phantom with a resolution of 5mm. The excitation used was a monopole on a metallic box positioned at the side of the head. The paper showed that metallic spectacles can re-distribute the energy, produced by the cell phone’s antenna, causing the efficiency to drop and the peak SAR to increase. Griffin [11] performed measurements with a phantom and metallic spectacles and showed that spectacles can increase or decrease the level of radiation near the eyes by up to 20dB due to shielding, enhancement and depolarisation effects. Anderson [12] also performed measurements with a phantom wearing metallic spectacles. With phones operating at 835MHz, held by the ear, the SAR in the eye closest to the phone was found to increase by up to 29%. Wang [13] modelled a monopole on a metallic box positioned by the ear of a human head wearing spectacles at 1.5GHz using the FDTD method. The average SAR in the eye increased by up to 2.7 times. The electric fields were shown to be small in between the frames but enhanced just above the frames. Wang postulated that these enhancements in the SAR in the head were due to the current on the spectacles. The novel area of head worn metallic jewellery illuminated by RF energy directed toward the front of the head will now be considered in greater detail.
2. DESCRIPTION OF MODEL

An independent 3D FDTD code [1] [2] has been written; see Taflove [14] for an excellent reference. Perfectly Matched Layers (PML), with geometric grading [15], 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 throughout this paper is 2mm. The lowest number of cells per wavelength was always greater than ten, and reasonable results have been obtained with only four [3]. The time step was 3.336pS. The simulations were run for ten cycles (1660 time steps at 1800MHz).

2.1. Dipole Source Irradiation

To allow comparison between simulations and measurements, a dipole model has been used in this paper. The dipole is horizontally orientated along the Y axis and fed at its centre with a sinusoidal CW source. The tangential E-field components are set to zero along the length of the dipole [14]. All results in this paper are normalised to 1W input power and the frequency of excitation is 1800MHz.

2.2. The Head Model

The results in section 3.1 of this paper used a 200mm cubic homogenous head, 100mm away from the dipole. The properties of the brain simulating tissue of the homogeneous head are (σ=1.37S/m, ε_r=40.48, ρ=1000kg/m³). The advantage of using a cubic head is that the metallic jewellery is a constant distance from the head. Removing the variables that describe the irregular shape and heterogeneous tissues of a human head simplifies the analysis of the effect of the pin. The results show that this can then be applied to more complicated geometries and the same pin behaves in a similar way when in proximity to different heads. Initially, using a cubic head also has the advantage that simulation results can be compared with the measurements made with the flat section of the SAM phantom. It is not possible to make measurements with the source in front of the face with the DASY4 system as the probe can not access the concave sections in the nose and eyes. Comparison of simulation and measurement techniques are discussed in section 3.2, and use a homogenous cubic head including a 2mm thick fibreglass shell.

In section 3.3, metallic jewellery is also added to an anatomically realistic head. An adult male head matrix provided by Brooks Air force was used (http://www.brooks.af.mil/AFRL/HED/hedr/hedr.html). The head is based on The Visible Human Project and has 25 tissue types. The head data has a 2mm resolution. The 3 geometries used in this paper are shown in Fig. 1.

2.3. Modelling The Metallic Pins

The metallic pins were modelled using metallic Yee cells, by setting the conductivity of the cells equal to the conductivity of copper [1]. Bernardi [8] used this technique to model metal shapes. Wang [13] modelled metallic spectacles by setting the conductivity of the Yee cells in the frames equal to titanium. The pins investigated in this report were 2mm thick (1 Yee cell) and of different lengths. The pins were orientated along the Y axis and therefore parallel to the dipole. We noted that a pin normal to the dipole had negligible effect.
3. RESULTS

3.1. Varying Pin Size and Distance from The Cube

Fig. 2 and Fig. 3 show the effect of adding metallic pins of different lengths and at different distances in front of a homogenous cubic head. A half-wave dipole, orientated along the Y axis, is positioned 100mm away from a homogeneous cubic head (no shell surrounds the head), see Fig. 1 (a). The metallic pin is positioned in front of the centre of the cube’s front face. The distance from the cube to the pin was varied from 0mm (pin touching head) to 50mm. The size of the pin was varied from 6 to 82mm. Therefore, the two figures show the same set of 520 permutations of pin size and location. Fig. 2 shows the 10g SAR results while Fig. 3 shows the 1g SAR results. The 1g and 10g graphs follow very similar trends except that the 1g SAR values are approximately double the 10g SAR values. By definition, the maximum 10g SAR is averaged over many more Yee cells and can not be larger than the maximum SAR averaged over 1g. The 10g SAR vs. length of pin and the 1g SAR vs. distance of cube to pin are not shown here.

Fig. 2 shows the results of different sized pins at distances from the cubic head as a function of the length of the pin. Small pins (<0.2 $\lambda$) have negligible effect on the 10g SAR regardless of the position of the pin. The effect of the pin becomes significant when the length is greater than 0.3 $\lambda$ (~50mm at 1800MHz). The effect of the pin increased with length and peaked at approximately 0.42 $\lambda$ long (70mm at 1800MHz). Note, also that the positioning of the same sized pin at different distances from the head also changes the 10g SAR. For a pin size greater than 0.42 $\lambda$ we noted a decrease in SAR.

Fig. 3 shows the same set of results as Fig. 2 except the results are now plotted as a function of the distance of the pin from the cube. The amplitude is increased as the figure shows the 1g values. Note that the results show that if the pin is touching the simulated brain tissue it has a negligible effect regardless of the size of the pin. As the pin was moved away from the cube the effect was seen to increase. The largest effect of the pin was seen to be at 12mm from the cube. Pins at larger distances can decrease the SAR averaged over 1g.

Fig. 2 highlights the effect of different sized pins positioned 12mm away from the cube and Fig. 3 highlights the effect of moving the 70mm pin (0.42 $\lambda$) away from the cube. The maximum 1 and 10g SAR was produced by the 70mm pin positioned 12mm from the cube. This combination increased the 1g SAR from 0.38 to 6.12W/kg. Therefore, the pin increased the 1g SAR by 1503% (increasing the SAR by 16.0 times). The same pin, increased the 10g SAR by 12.8 times from 0.25 to 3.25W/kg. As shown above, a metallic pin can also decrease the SAR in the cube. The minimum SAR occurred when a 78mm pin was positioned 50mm from the cube. In this case, the 1g SAR is reduced from 0.38 to 0.05W/kg, a reduction of 86% compared to the value with no pin. The 10g SAR is reduced by 89% from 0.25 to 0.027W/kg.

3.2. Measurements Of SAR With DASY4 System

The effect of the pin was measured using the flat section of the SAM phantom of the DASY4 measurement system [17]. To directly compare the simulations with the measurements, the dipole in the FDTD code was changed to be 70mm in length. The 200mm cubic phantom was modified to include a 2mm thick fibreglass shell ($\varepsilon_r=3.5$, $\sigma=0$S/m). A 70mm long pin was positioned 10mm away from the surface of the phantom.
and orientated parallel to the dipole, see Fig. 1 (b). The shell was 98mm from the centre of the dipole. The measurement set-up is shown in Fig. 4. Note the dipole in the measurements was 72.5mm long and had a diameter of 3.66mm. The pin was attached to the flat phantom using cotton and celotape, which when clean are assumed to be invisible at these frequencies. Plumb lines and lasers were used to ensure that the alignment and position of both the pin and dipole were as accurate as possible.

In the FDTD simulation of this geometry, the pin increased the 1g SAR by 13.1 times from 0.40 to 5.24W/kg and the 10g SAR by 10.3 times from 0.27 to 2.74W/kg. The measurements showed that the pin increased the 1g SAR by 11.5 times from 0.45 to 5.17W/kg and the 10g SAR by 9.7 times from 0.29 to 2.79W/kg. Both techniques show good agreement with each other and the measurements confirm that the effect of the pin on the mass averaged SAR is significant. Results are shown for the local SAR along two different axes for the simulations and measurements in Fig. 5 (Z axis, perpendicular to pin) and Fig. 6 (Y axis, parallel to pin). The SAR is calculated 1mm into cubic liquid for FDTD simulations and extrapolated to 1mm into the liquid for DASY4 measurements. The simulation results show good agreement with the measurements. The figures show that the pin increased the local SAR at the centre of the cube and decreased it towards the edges of the cube. The local SAR 1mm into the brain simulating tissue, is increased in a central rectangle and decreased outside this region. This rectangle is parallel to the pin and has dimensions of 88 x 44mm.

3.3. Horizontal Pin Near Realistically Shaped Homogenous And Heterogeneous Heads

To investigate the effect of the shape and electrical properties of the head, when in proximity to jewellery, a metallic pin was added to a realistically shaped head. The dipole and pin were positioned at the height of the eyebrows and 80mm in front of the tip of the nose, see Fig. 1 (c). The horizontal metallic pin was added 12mm in front of the eyebrows. This geometry could represent the cross piece of a pair of rimless spectacles. The identical external geometry used for the Brooks head was used to create a homogenous head by assigning all tissues (including internal air) to have the properties of brain ($\varepsilon = 40.48$, $\sigma = 1.37$S/m).

Fig. 7 shows the relative enhancement (SAR with pin/SAR without pin) of the 10g SAR while varying the length of the pin near the forehead of realistically shaped homogenous and heterogeneous heads. The results are similar to the ones with the pin and the cube.
shown in Fig. 2. The pin has a significant effect on the maximum 10g SAR when the pin is approximately 0.42 \( \lambda \) long and there is relatively little effect with much shorter or much longer pins. Note there is no secondary resonance when the pin is approximately 0.25 \( \lambda \) or 1 \( \lambda \) long. The 70mm long pin, positioned 12mm from the homogeneous head, increased the 1g SAR by 5.9 times from 1.51 to 8.88W/kg. The same pin increased the 10g SAR by 4.9 times from 0.93 to 4.50W/kg. The relative enhancement in SAR due to the pin is smaller in the heterogeneous Brooks head than for the homogeneous version of the same head. The pin increased the 1g SAR in the Brooks head by 2.5 times from 2.11 to 5.21W/kg. The same pin increased the 10g SAR by 2.9 times from 0.96 to 2.78W/kg.

The bottom of the sinuses (in white) can be seen in Fig. 1 (c). They contain internal air and are located close to the forehead and above and in-between the eyes. The proximity of the pin to the large internal air cavities was considered as a possibility for the lower relative enhancement of the SAR due to the pin in the heterogeneous head model. To test this hypothesis, the homogeneous Brooks head was altered to include internal air in the sinus location. The pin increased the 1g SAR by 6.7 times from 1.48 to 9.87W/kg in the homogeneous head with internal air. The 10g SAR was increased by 5.7 times from 0.79 to 4.56W/kg. The inclusion of internal air in the homogeneous head decreased the 10g SAR with no pin and increased the relative enhancement of the pin. The homogeneous Brooks heads with and without internal air have larger relative enhancements in SAR due to the pin than the heterogeneous head, see Fig. 7. Therefore, the reduced effect of the pin with the heterogeneous compared to the homogeneous head is due to the different tissue properties and not due to the internal air cavities.

4. CONCLUSIONS

This paper has investigated the effect of metallic pins on the SAR in the head. Significant increases have been found. The 1g SAR was found to increase by up to 16 times and the 10g SAR by 12.8 times for cubic heads. The effects were negligible when small pins were touching the conducting surface of the cubic head and were small when the pin was very close to the head. This suggests that body worn jewellery, lying on the surface of the skin, may have little effect on the SAR in the head. The results indicate that metallic jewellery insulated from the head by air or a plastic coating may have a greater effect. Our results have shown that metallic objects positioned several millimetres away from the head had the most significant effect. Such objects could include metallic spectacles, microphones and nose and ear jewellery that may hang away from the head. The metallic pins were found to have the maximum effect when they were approximately 0.42 \( \lambda \) long. Longer metallic pins further from the head can also significantly decrease the maximum SAR in the head. Statistically it was found that the majority of pin lengths and pin locations increased the 1 and 10g SAR in the cubic head but by less than a factor of two. This concludes to the pin causing a redistribution of the energy in the head away from the edges towards the centre.

Similar mechanisms were found with an anatomically realistic head. The shape and internal tissues of the head were found to have an important effect on the SAR. The relative enhancement of the pin on the 1g SAR was reduced from 16 for the homogenous cube to 6.8 times for the homogeneous realistically shaped head and further reduced to 2.5 times with the heterogeneous head. Thus, cubic heads and homogenous phantoms may over-estimate the effect of metallic jewellery.

5. REFERENCES

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