A STUDY OF CHANGES TO SPECIFIC ABSORBTION RATES IN THE HUMAN EYE CLOSE TO PERFECTLY CONDUCTING SPECTACLES WITHIN THE RADIO FREQUENCY RANGE 1.5 TO 3.0GHZ

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ABSTRACT

This paper investigates changes in specific absorption rates due to metallic spectacles in close proximity with a head of representative electrical properties. Here, the FDTD method is used with a Z directed plane wave to simulate a personal digital assistant held in front of the face. Results confirm that metallic spectacles can significantly change SAR levels at frequencies between 1.5 and 3GHz. Specific attention is given to the energy interaction in the eyes and the nose. Results are given for several common spectacle frame shapes as well as whole head energy absorption comparisons.

INTRODUCTION

The study of interactions between biological material and the energy generated by personal communications handsets is currently topical. This paper investigates the possible relative effects that radio enabled personal digital assistants (PDAs) may be for users with and without metallic spectacles. A rigorous Finite-Difference Time-Domain (FDTD) model is used here to investigate electromagnetic waves interactions with biological material. Much work has been done regarding mobile phones positioned near the ear, but limited work has been done irradiating the head from the front. Dimbylow and Hirata have illuminated the head with a plane wave from the front [1, 2] and have previously found resonance in the eyes within typical cellular spectra. The frequency range considered for this paper, 1.5 to 3GHz, is now common in mobile communications networks.

Bernardi [3] considered the eyes to be particularly sensitive organs due to their proximity to the surface and are particularly at risk to thermal damage. This portion of the head has relatively little blood flow to carry heat away. Clearly, eyes are also more vulnerable when the excitation is from the front of the head as is the case with such hand-held PDAs. In the same area Cooper [4], modelled a geometric head, and Bernardi [5] 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 [6] considered metal implantations inside the head and found that they increased the Specific Absorption Rate (SAR) in the surrounding region. These papers show that metal objects close to biological matter may increase SAR in that matter. Spectacles have not previously been reported in the literature, however Bernardi [3] did model a glass lens in 2D.

DESCRIPTION OF MODEL

An independent 3D FDTD code has been written, see Taflove [7] for an excellent reference. Perfectly Matched Layer (PML), with geometric grading [8], absorbing boundary conditions are used to terminate the grid. The PML is eight cells thick and is positioned ten cells from the head. The FDTD grid size is 174x140x140 cells in the X, Y and Z dimensions. A plane wave is injected into the grid using the total field / scattered field approach [7]. This produces a Z directed plane wave travelling in the X direction (from the nose to the rear of the head). See Figure 1 for orientation of the axes. The power density used is 50W/m², the maximum permissible exposure limit for controlled environments and is the same as in Hirata [2].

The digital head taken from Brooks Air force [9] has a resolution of 2mm. Hence a cubic Yee cell with side of length 2mm is used. Strictly speaking the Courant sampling criteria of ten cells per wavelength is not satisfied at these spectra. However the lowest number of cells per wavelength is always greater than six, and reasonable results have been obtained with only four [1] The head is composed of 25 different materials of which cornea, humor, sclera and lens make up the eye. Although the Brooks head is not exactly symmetric, a line of symmetry, in the Y direction, has been included in this model to save memory and computational time. N.B. Figures 1 and 7 in this paper show half the head mirrored to aid visualisation of the problem This assumption of symmetry has been found to have negligible effect. It should be noted that the head model has closed eyelids and the results in this paper are calculated with the eyelids kept closed.

The dielectric properties are calculated with aid of the 4-Cole-Cole extrapolation [10] and are frequency dependant. At the interface between two materials, the average values of conductivity and permitivity are used. The densities of the different materials are the same as used by Mason [11].

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

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

Where $|E|^2$ is the root mean square of the electric field components, ρ is the density of the material in kg/m^3 and σ is the conductivity in S/m. Each E_x, E_y and E_z values are assumed to be at the centre of the cell, is averaged over 4 components. Hence each Yee cell is bounded by 12 electric field components. The one gram averaged SAR, SAR_{1G}, comparable with the FCC safety limits of 1.6W/Kg, is also calculated, by summing the local SAR in each cell until the total mass is just over a gram and dividing by the number of cells.

Modelling the Spectacles.

The spectacles were modelled using metallic Yee cells, by setting the conductivity of the cells equal to the conductivity of copper; 59610000S/m. Four typical different frame types were researched: square (external dimensions of 36mm x 36mm in Y and Z axis), circular (44mm x 44mm), rectangular (48mm x 28mm) and elliptical (48mm x 28mm). See figure 1 for orientation and geometry.

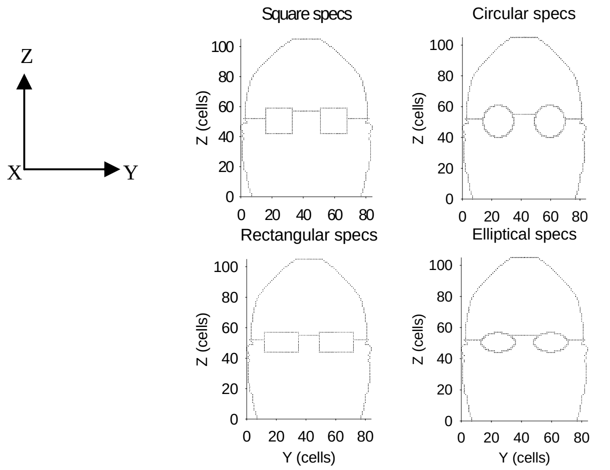

Figure 1. The Orientation and coordinate system used. The four types of spectacles: square, circular, rectangular and elliptical are shown relative to the outline of the head.

In each case the centre of the lens was positioned at the centre of the eye in the Y – Z plane, and 2.6cm in front of the cornea. The cells between the frames were assigned a relative permittivity of 2.56, thereby including a realistic Perspex lens 2mm thick. In addition to these basic geometric shapes, a nosepiece and a strut to the arm were included - see Figure 1. Care was taken to ensure that the frames did not lie inside the head or touch the skin. Spectacle arms were modelled as a line of single metallic Yee cells, extending 14cm in the X direction, touching the head above the ear.

By comparing the average SAR in the head illuminated with E_z and E_y plane waves with results from Hirata [2], the FDTD code and the digital head model were validated - see Figure 2.

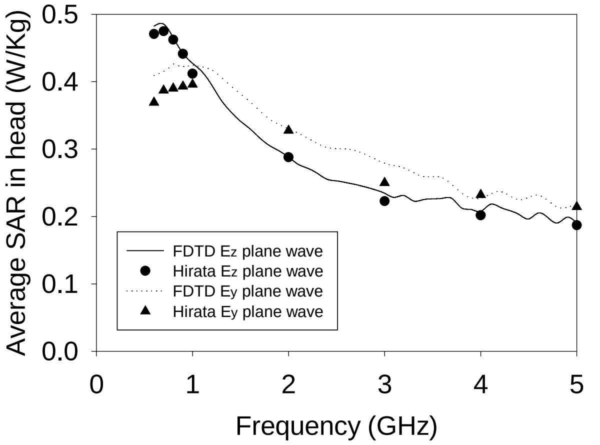

Figure 2. The average SAR in a head illuminated by a $50W/m^2$ Ez and Ey plane wave, compared to published paper [2].

From the figure is can be seen that agreement between the model developed by the authors and those of [2] is generally good for both polarisations of plane wave.

RESULTS

To examine the effect of adding metallic spectacles, three different criteria were investigated; the maximum local SAR in a single cell, the SAR_{1G} averaged over one gram and the average SAR in the eye.

Maximum Local SAR in a Yee cell

Figure 3 shows the maximum local SAR in any one Yee cell in the head as a function of frequency over the important range of 1.5 to 3GHz. The unbroken line shows SAR in the head without any spectacles. It can be seen from the figure that all of the four shapes of spectacle investigated give similar effects in local SAR but that this effect is shifted in frequency. For example at 2.6GHz elliptical spectacles effectively double the maximum local SAR in any one yee cell in the head. The addition of metal spectacles generally gives an increased maximum local SAR over the frequency range considered. In terms of location it was found that the position of the maximum SAR shifts from the skin at the front of the nose when no spectacles are present, to the skin close to the metal edges of the spectacles. Either on the side of the nose or on the side of the head next to the metallic arms.

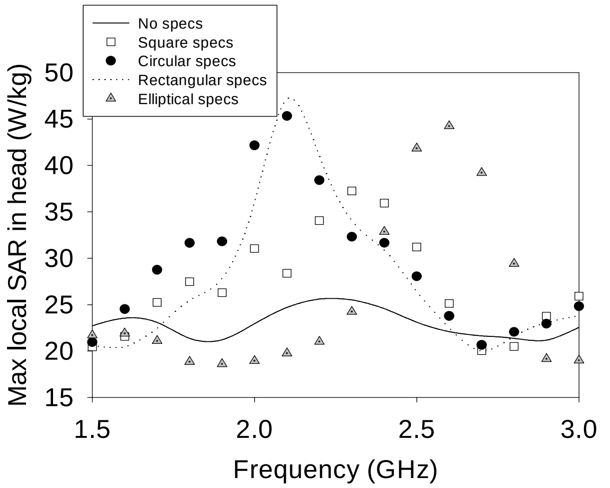

Figure 3. The maximum SAR in any cell in the head, with and without spectacles.

Figure 4 shows that the maximum local SAR in the eye is increased by the addition of metal spectacles below 2.2GHz and decreased above this frequency. Elliptical frames however make the eye resonate at 2.3Ghz. The existence of both increases and decreases in maximum SAR is due to the constructive and destructive interference of the electromagnetic waves interacting with the metal frames. The position of the maximum is relatively unchanged, and is located in the sclera or humor, centrally in the X-Y plane and towards the top of the eye.

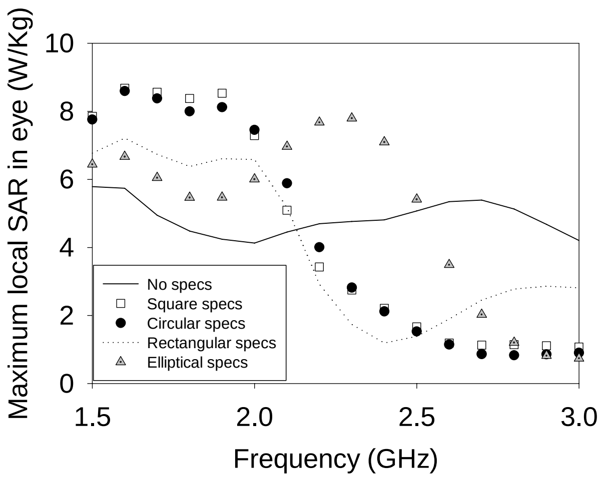

Figure 4. The maximum SAR in any cell in the eye with and without spectacles.

Maximum SAR In The Eye Averaged Over 1g

The maximum SAR_{1G} in the eye has similar characteristics to the maximum local SAR – see Figure 5. Metallic spectacles increase the SAR_{1G} below 2.2GHz and decrease it above this frequency. Elliptical spectacles again cause resonance at a slightly higher frequency. The amplitude of the SAR_{1G} is lower than the maximum SAR by a ratio of approximately 1.5.

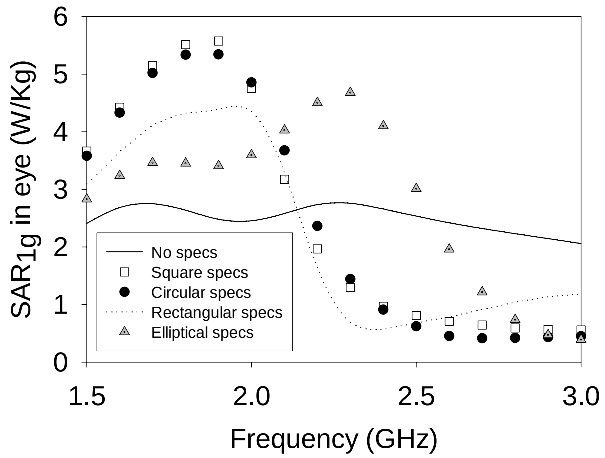

Figure 5. The maximum SAR averaged over 1g in the eye.

Average SAR In The Eye

Figure 6 shows the SAR averaged over the whole of the eye. The eye in this model has a mass of 8.37g and is comparable to the ICNIRP safety standard of 2W/Kg averaged over 10g. The average SAR in the eye exhibits similar behaviour to the values of SAR_{1G} in Figure 5, except the amplitude of the SAR averaged over the eye is very closely equal to half SAR_{1G}.

The maximum effect of metallic spectacles is with square frames at 1.9GHz, which result in an increase of approximately 120% compared to no spectacles. However adding spectacles can also decrease the average SAR in the eye for the spectra considered here, particularly at higher frequencies. Elliptical spectacles at 3GHz reduce the power absorbed in the eye by approximately 80%.

All four frames examined increase and decrease (depending on the frequency) the power absorbed in the whole head by approximately 10%. The maximum increase in the power absorbed in the head is with square frames at 1.9GHz, which results in an increase of approximately 13%.

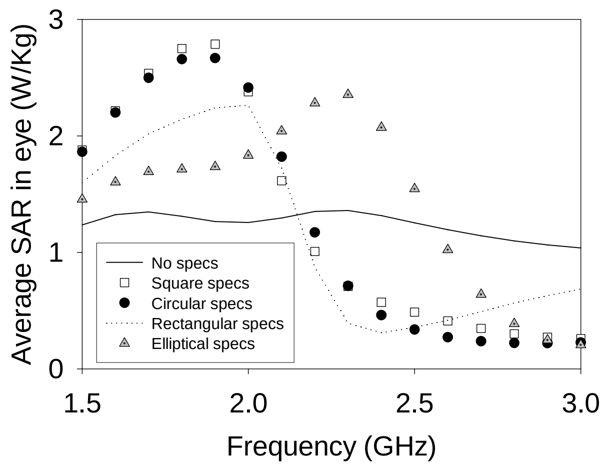

Figure 6 SAR averaged over eye with and without spectacles.

Figure 7 represents the difference that square spectacles make to the SAR at 1.9GHz in a horizontal cross section through the centre of the eyes. The figure shows that at this frequency the effects are larger towards the front of the head, close to the metal frames. As predicted there is a large increase in SAR in the eyes, but the greatest increase due to the spectacles is in the nose. This is explained due to the nose containing tissues with relatively high conductivity, notably skin, muscle and mucous membrane. At the cross section through the eyes, the effects of spectacles are relatively superficial and they make little difference in the region located behind the eyes and the nose.

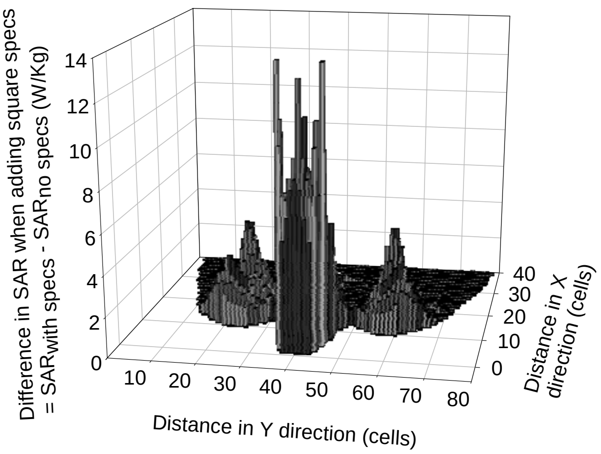

Figure 7. The increase (or decrease) when adding square spectacles at 1.9GHz compared to no spectacles, shown as a cross section through the middle of the eyes. The graph shows that there is a large increase in the local SAR in the nose and the eyes, but little change further into the head in the X direction.

CONCLUSIONS

The results presented in this paper show that metallic spectacles can substantially change the SAR in the head, over the frequency range 1.5 to 3GHz, when excitation is from the front. The SAR averaged over the eye has been to vary by an approximate increase of 120% and an approximate decrease of 80%. Increases of around 10% are possible for the entire head. The four shapes of spectacles investigated gave similar magnitudes of maxima and minima at varying frequencies. The differences between them can be explained by the different sizes and orientations of the metal Yee cells in the frames and by the different distances to the head. Substantial increases and decreases in the power absorbed in the eyes have been reported on and it is considered likely that different spectacles at different distances from the eye will give even larger effects. Further work will include a search for significant combinations.

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