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IMPLICATIONS FOR SAR WHEN USING A SYMMETRIC PHANTOM EXPOSED TO RF RADIATION USING THE FDTD METHOD

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Abstract—this paper investigates the implications of SAR when using a symmetric head compared to a whole head. The excitation is a vertically polarised plane wave traveling from the front of the face to the back of the head. The frequency range considered is 1.5 to 3.0GHz. In general actual human heads are not symmetric. For example one eye may be slightly higher than the other and a nose maybe somewhat bent. Recently researchers also have evidence of brain torque (i.e. rightward frontal and leftward occipital asymmetry) in humans. In this FDTD model the head is modeled as two identical mirrored halves. By this method the field values need not be calculated twice thereby reducing computation time and memory requirements. Our results show whole head versus mirrored head comparisons for the maximum 1 and 10g SAR in the head and gives particular attention to the SAR in the eyes.

Index Terms—FDTD, SAR, eye, symmetry

I. INTRODUCTION

The study of interactions between biological material and the energy generated by personal communications devices is currently topical. This paper investigates the effects of symmetry with a CW source positioned in front of the head. A rigorous Finite-Difference Time-Domain (FDTD) model is used. In recent years some work has been written up regarding mobile phones positioned near the ear [1-4]. The head has also been irradiated from in front of the eye using realistic mobile phone models [3-5]. This is topical as such hand held devices held to the front of and away from the head may soon become popular. Dimbylow and Hirata have illuminated the head with a plane wave from the front [6, 7] and have previously found resonance in the eyes within typical cellular spectra. Bernardi [8] considered the eyes to be particularly sensitive organs due to their proximity to the surface of the head and the their relatively low levels of blood flow when compared to other regions of the body. Dimbylow [3] also stresses the vulnerability of the eyes as they have a tendency to accumulate damage and cellular debris. EM modeling is computationally expensive; it is therefore advantageous to use symmetry which can reduce computational costs.

II. DESCRIPTION OF MODEL

An independent 3D FDTD code has been written; see Taflove [9] for an excellent reference. Perfectly Matched Layers (PML), with geometric grading [10], 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 was 174x140x140 cells in the x, y, and z dimensions.

A plane wave is injected into the grid using the total field / scattered field approach [9]. This produces a z polarised plane wave propagating in the x direction (from the nose to the rear of the head). See Fig. 1 for orientation of the axes. The power density used was 50W/m², the maximum permissible exposure limit in controlled environments [7].
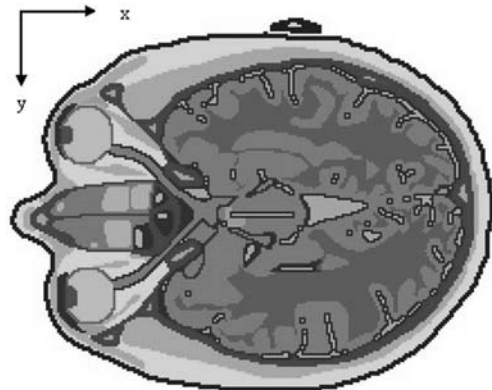

Fig. 1. A cross section through the eyes of the Brooks head of 2mm resolution.

A head matrix provided by Brooks Air force [11] was used. The head, which is based on MRI data, is that of an adult male and has twenty-five tissue types. Fig. 1 shows a cross section of the 2mm head through the centre of the eyes. The layer of fat, muscle and skin in front of the eye can be seen which make up the eyelids. It should be noted that the Brooks head has closed eyelids and the results in this paper are calculated with the eyelids kept closed. Hirata showed [3] that opening the eyelid increased the average SAR in the eye by 15% at 5.0GHz.

The size of the Yee cell was 2mm, equal to the resolution of the head. The lowest number of cells per wavelength was always greater than six, and reasonable results have been obtained with only four [6].

Fig. 1 shows that the Brooks head is not exactly symmetric; for example there are visible differences in the eyes, sinuses and the top of one ear is higher than the other. A line of symmetry, in the *x-z* plane, has been included in this model to save memory and computational time. This plane of symmetry runs vertically down the centre of the nose and extends to the back of the head. This was achieved by replacing the mid-plane of the grid with a magnetic wall [7, 12], and thus assuming the other half of the head is identical.

The dielectric properties are calculated with aid of the 4-Cole-Cole extrapolation [13] and are frequency dependant. At the interface between two materials, the average values of conductivity and permittivity are used. The densities of the different materials are the same as used by Mason [14].

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

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

Where $|E|^2$ is the root mean square of the electric field components, ρ is the density of the material in Kg/m³ and σ is the conductivity in S/m. The SAR is calculated with the twelve-field approach as used by Caputa [15].

In previous works [16] the FDTD, code including the PML absorbing boundary conditions, has been validated. The average SAR in an anatomical head excited with *Ez* and *Ey* polarized plane waves as a function of frequency showed good agreement with Hirata [7].

III. RESULTS

To examine the effects of symmetry, four metrics were investigated; the maximum local SAR in a single cell, the average SAR in the eye, the SAR_{1G} averaged over one gram and the SAR_{10G} averaged over ten grams. The SAR_{1G} and SAR_{10G} have been averaged over a cubic volume containing no air [15] and have been calculating assuming the head is symmetric.

A. Average SAR in the Eye

The eye in the Brooks model has a mass of approximately 8.37g and is comparable to the ICNIRP safety standard of 2W/Kg averaged over 10g [17]. The Brooks head is not symmetric as demonstrated by the left eye having a

different average SAR from the right one, see Fig. 2. In this research the right eye (as seen from the front) has been arbitrarily chosen to used the symmetric model. There is little change in the average SAR in this eye when the whole head is modelled as against that when symmetric half head is modelled.
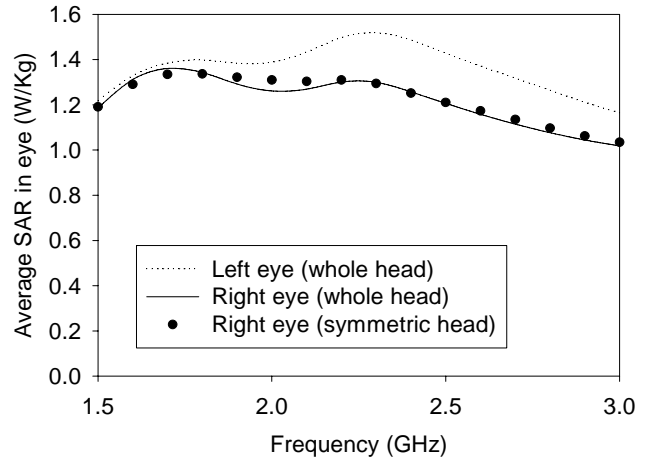

Fig. 2. The average SAR in the eye with and without symmetry.

B. Maximum SAR in the Eye Averaged Over 1g

The maximum SAR_{1G}, is comparable with the ANSI/IEEE standards of 1.6W/Kg [18]. Results for the eye are shown in Fig. 3. Again there is a difference in SAR between the two eyes, but the effect of symmetry has negligible effect on the right eye when using this smaller averaging volume
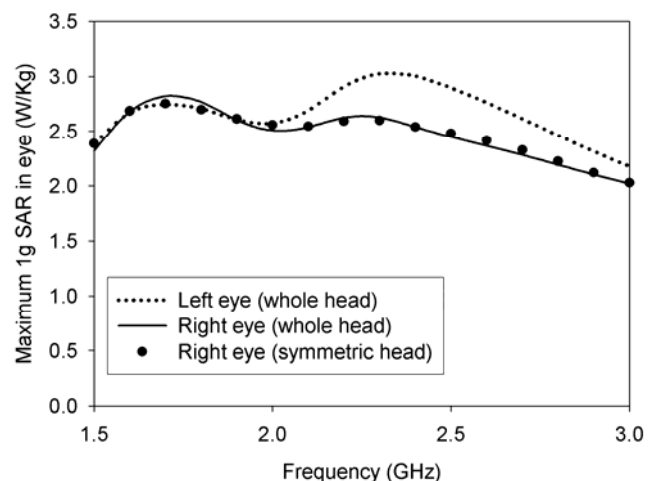

Fig. 3. The maximum 1g SAR in the eye with and without symmetry.

C. Maximum SAR in an individual Yee cell in the eye

The maximum SAR in an individual Yee cell in the eye is shown in Fig. 4. Reasonable agreement is found between the whole and symmetric heads. The SAR in one cell is extremely sensitive and is thus only an indicative measure of the SAR in the head. Fig. 4 shows the effect of symmetry is only an approximation, which becomes more accurate as a larger volume of the eye is considered.
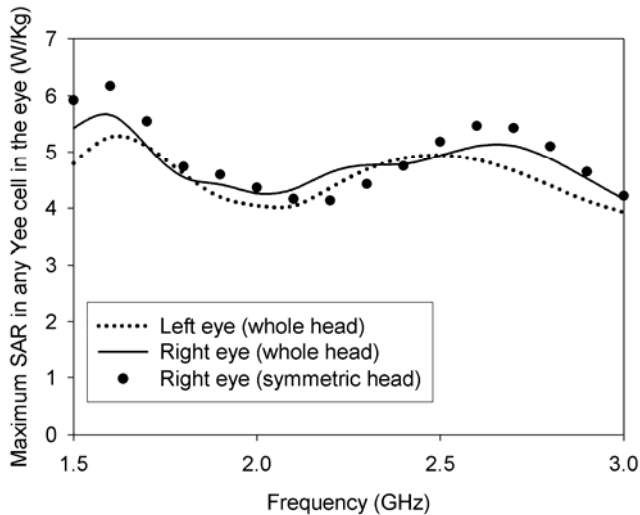

Fig. 4. The maximum SAR in a single cell in the eye with and without symmetry.

D. Maximum 1g SAR in the head

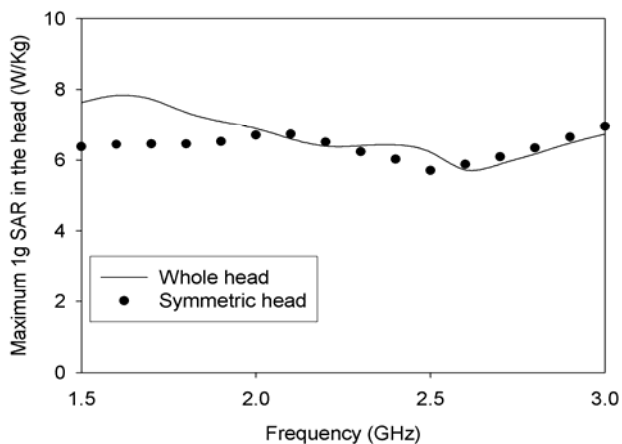The maximum 1g SAR in the head is shown in Fig. 5.

Fig. 5. The maximum 1g SAR in the head with and without symmetry.

There is reasonable agreement of this metric with the whole and symmetric heads. The effect of symmetry becomes small above 2GHz. The maximum SAR exists in the nose near the plane of symmetry, thus the averaging volume of the whole head may contain different tissues compared to the symmetric head.

E. Maximum 10g SAR in the head

The maximum 10g SAR in the head is shown in Fig. 6. Results are similar to the 1g SAR values in Fig. 5. The agreement is generally reasonable above 2GHz.
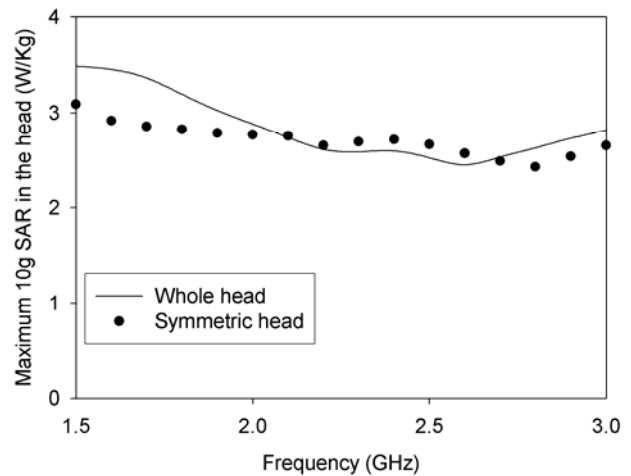

Fig. 6. The maximum 10g SAR in the head with and without symmetry.

IV. CONCLUSIONS

The assumption of using a vertical plane of symmetry in the head excited from the front allows reductions in the computational runtime and memory requirements. Applying symmetry causes negligible loss in accuracy of the SAR in 1g of the eye and SAR averaged over the whole eye. The maximum 1g and 10g SAR in a symmetric head provide reasonable results above 2GHz. Below this frequency the approximation of symmetry becomes less accurate. When the excitation is from the front the maximum SAR values are often located on the central symmetry plane. Therefore the mirrored symmetric head may contain different tissues from the whole head. Also the exterior shape of the nose may not be symmetrical.

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