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# SPECIFIC ABSORPTION RATES IN THE HUMAN HEAD DUE TO CIRCULAR METALLIC EARRINGS AT 1800MHZ

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**Abstract:** This paper investigates Specific Absorption Rates (SAR) in the human head due to circular metallic earrings at 1800MHz. A Finite-Difference Time-Domain (FDTD) code was used to analyse different sizes and positions of circular earrings near a homogenous cubic phantom. Results showed good agreement with measurements using the flat section of the SAM twin phantom with the DASY4 measurement system. The excitation was a half wave dipole. Metallic loops with a circumference of approximately one wavelength and positioned 14mm away from the phantom increased the 10g SAR by 5 times. The FDTD code has also been used to analyse the effect of metallic earrings when ‘pierced’ through the ear of an anatomically realistic digital human head based on the Visible Human Project. The head is not symmetric and both ears were considered to allow comparison between different heads. The shape of the ear and the size of the earring were found to be very significant when earrings were hung from the human ear.

## 1. Introduction

There is concern that the radiation from mobile phones may adversely affect human health. 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 loops hung from the ear. A rigorous FDTD model is used to model a CW source positioned by the ear.

In recent years, work has been presented regarding mobile phones positioned near the ear [3] [4]. See [1] for a more complete review of bioelectromagnetics and the effect of metallic objects.

The authors [5] have previously researched the effect of metallic jewellery positioned in front of the face and excited with a communications enabled personal digital assistant device. Fayos-Fernandez [6] found metallic earrings increased the SAR using a dipole source positioned by the ear. He considered arcs, pins and small metallic studs. Recently, Virtanen [7] found that metallic implants inside the head could increase the SAR. He investigated metallic loops and pins inside a cylindrical head. Tay [8] 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.

Troulis [9] 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. Anderson [10] 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 [11] modelled a monopole on a metallic box positioned by the ear of a human head wearing spectacles at 1500MHz using the FDTD method. In the same area, the effect on SAR in geometric and anatomical heads by nearby metallic walls [12] [13] and metallic implants [14] [15] has also been investigated.

## 2. Description of model

An independent 3D FDTD code [1] [2] has been written. Perfectly Matched Layers (PML) 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].

To allow comparison between simulations and measurements, a dipole model has been used. The dipole is fed at its centre with a sinusoidal CW source. The tangential E-field components are set to zero along the length of the dipole [1]. All results in this paper are normalised to 1W input power and the frequency of excitation is 1800MHz. The dipole in the FDTD simulations is 74mm long.

The metallic loops were modelled using metallic Yee cells, by setting the conductivity of the cells equal to the conductivity of copper [1]. Bernardi [13] used this technique to model metal shapes. Wang [11] modelled metallic spectacles by setting the conductivity of the Yee cells in the frames equal to titanium. The earrings investigated in this report were 2mm thick (1 Yee cell) and of different diameters.

The results in this paper used a 200mm cubic homogenous head, 40mm away from the dipole. The properties of the brain simulating tissue of the homogeneous head are ( $\sigma=1.37\text{S/m}$ ,  $\epsilon_r=40.48$ ,  $\rho=1000\text{kg/m}^3$ ). The brain fluid is surrounded by a 2mm thick fibreglass shell ( $\sigma=0\text{S/m}$ ,  $\epsilon_r=3.5$ ). The advantage of using a cubic head is that the metallic jewellery is a constant distance from the head and the simulation results can be compared with DASY4 measurements made with the flat section of the SAM twin phantom [16]. The length of the dipole used in the measurements was 72.5mm and had a diameter of 3.66mm [5], see Fig. 1.

Metallic jewellery has also been 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>) [1]. The head is based on The Visible Human Project and has 25 tissue types. The head data has a 2mm resolution. The densities and dielectric properties of the tissues in the Brooks head at 1800MHz are shown in [2]. SAR is the standard criteria to measure the amount of electromagnetic energy absorbed in the body and is calculated as in Eq. 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,  $\rho$  is the mass density of the material in  $\text{kg/m}^3$  and  $\sigma$  is the electrical conductivity in  $\text{S/m}$ . The SAR is calculated with the twelve-field approach [1].

### 3. Results

Initially, the FDTD code was used to search for the maximum effects of adding a metallic circular ring near to the homogeneous cubic phantom. The dipole was positioned 40mm from the surface of the fibreglass shell. The centre of the dipole was placed below the centre of the loop, see Fig. 1 for the equivalent measurement setup. The results are shown in Fig. 2 for different sizes of loop at different distances from the cube. There was negligible increase in the 1g SAR when the loop was touching the surface for all the sizes of loop investigated. The loop began to have a significant effect as it was moved away from the surface. The largest 1 and 10g SAR values were found with the loop 12 to 16mm away from the cube and when the circumference of the loop was approximately one wavelength.



Figure 1. A circular ring and dipole positioned under the flat section of the SAM twin phantom.

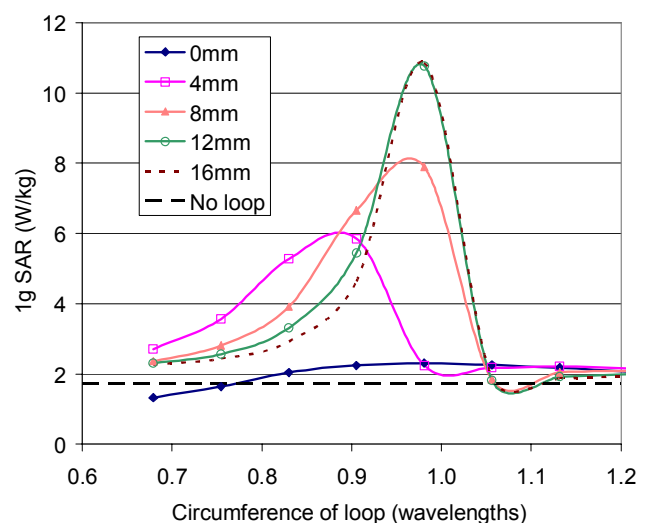


Figure 2. FDTD simulations of different sized loops at different distances from a cubic phantom.

A loop with an external diameter of 52mm and positioned 14mm from the phantom produced the highest 1g SAR. This combination was used to measure the SAR in the flat section of the SAM twin phantom using the DASY4 measurement system [16], see Fig. 1. The results for the 1 and 10g SAR for the measurements and simulations along with Microstripes commercial software [17] are shown in Table 1.

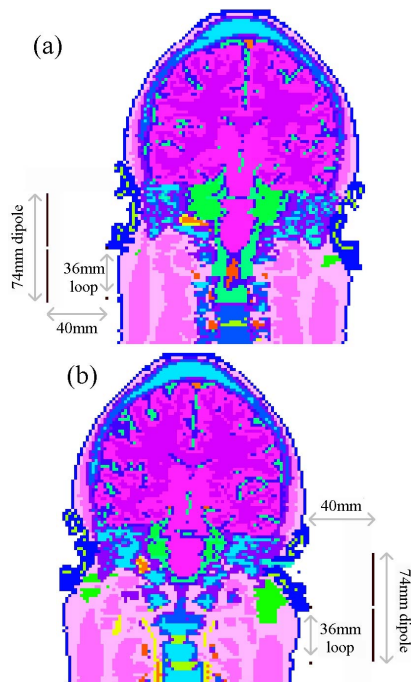
**Table 1. The 1 and 10g SAR in a flat/cubic phantom with a 52mm diameter loop, 14mm from the surface.**

	FDTD No loop	DASY4 No loop	Microstripes No loop	FDTD 52mm loop	DASY4 52mm loop	Microstripes 52mm loop
1g SAR (W/kg)	1.74	1.70	1.60	11.03	10.23	10.09
10g SAR (W/kg)	1.05	1.06	1.09	5.73	5.71	5.97

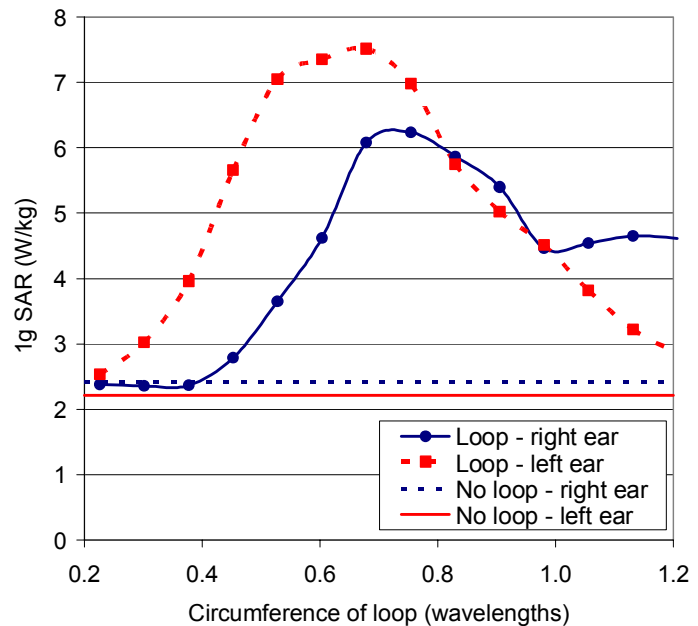
The results in Table 1 show that a metallic ring can significantly increase the SAR in the head. The 52mm diameter ring, 14mm from the cube increased the 1 and 10g SAR by more than five times. Table 1 shows there is good agreement between the simulations, measurements and commercial software. The maximum SAR values were not found at the centre of the ring but occurred by the edges of the ring on either side of the dipole.

Circular earrings were also added to an anatomically realistic digital human head. The head is not symmetric and so earrings were added to each ear separately. The earring pierced the ear in the model. This meant the bottom cell of the ear was replaced by the metallic loop, see Fig. 3. The earrings hung down beside the head. The centre of the dipole was positioned 40mm away from the top of the ring, see Fig. 3.

The results of different circumferences of earring are shown in Fig. 4. Earrings can increase the 1g SAR by 3.5 times in the anatomical head. The ears are different shapes and therefore the same earring may behave differently on different ears. The close proximity of the head caused the ring to produce the largest 1g SAR values when the circumference was approximately  $0.65\lambda$  not  $\sim 1\lambda$ . A similar phenomenon was also found with the cubic head, see Fig. 2. The effect of the earring on the 10g SAR was not as significant and the range of ring sizes investigated had negligible effect on the 10g SAR when the loop was by the right ear.



**Figure 3. 74mm dipole 40mm from left (a) and right (b) ears of Brooks head with circular earring.**



**Figure 4. FDTD results of adding circular rings of different sizes to either side of the Brooks head.**

#### 4. Conclusions

The FDTD method was used to investigate the SAR in the presence of circular metallic earrings. The earrings caused the largest SAR in the head when the ring was approximately 1 wavelength in circumference and

positioned away from the cube. Simulations agreed well with measurements. Metallic earrings produced smaller but still significant increases in the SAR in an anatomical model of a human head. The geometry of the ear and the surrounding tissues were found to be very important in determining the effects of the earring. The amplitude of the SAR and the resonance size of the ring can vary from ear to ear. Therefore, it may be difficult to investigate the effects on different people and a homogeneous cubic phantom may represent a worst case scenario for the effects of metallic circular earrings.

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