Effects of metallic semi-rimmed spectacles on SAR in the head from a 900MHz frontal dipole source

Effects of metallic semi-rimmed spectacles on SAR in the head from a 900MHz frontal dipole source

Konstantinos Stergiou[#], Chinthana Panagamuwa[#1], William Whittow[#2], Rob Edwards[#3]

[#]*Electronic and Electrical Engineering Department, Loughborough University, Loughborough, LE11 3TU, UK*

[1]C.J.Panagamuwa@lboro.ac.uk, [2]w.g.whittow@lboro.ac.uk, [3]r.m.edwards@lboro.ac.uk

Abstract— **This paper examines the effects of metallic semi-rimmed spectacles on the specific absorption rate (SAR) inside the head when illuminated by a frontal dipole source representing a PDA held in front of the face. The frequency considered is 900MHz. Both children's and adult's spectacles are investigated using the Loughborough SAM (Specific Anthropomorphic Mannequin) head incorporated into a DASY4 robot measurement system. The spectacles are tested with and without their arms. For comparison, simulations of the SAM head using FDTD have been conducted. Results show children's semi-rimmed spectacles may be resonant at 900MHz and may have a focusing effect that redistributes the SAR in the head.**

I. Introduction

Hand held mobile communications equipment (MCE) are now widely used throughout the world. In order to minimise the heating caused in the user by RF energy absorption, all MCE must meet maximum transmit power regulations. SAR is used as the method of evaluating energy absorption rates in tissue and spatially averaged SAR limits have been adopted worldwide, for example, 1.6W/kg over 1g in the USA [1] and 2W/kg over 10g in Europe [2].

Although RF emissions from MCE are carefully regulated, there exists the possibility that metallic objects inside or on the surface of the body, when illuminated by radio frequency energy may focus energy thereby in some cases increasing local SAR in the body. In the past, items such as medical implants have been shown to increase the energy absorbed [3]. External metallic objects such as earrings [4], piercings [5] and spectacles [6] have also been studied.

At Loughborough University, the authors have been considering the specific case of semi-rimmed spectacles (see Figure 1). In recent years, this type of spectacle has been widely adopted as prescription glasses and sunglasses. Furthermore, with recent advances in technology, MCE are incorporating a number of applications that require the device to be held in front of the face whilst transmitting. This introduces a new scenario whereby the user is exposed to a frontal radiation source which could couple to the semi-rimmed spectacle. The significance of the semi-rimed spectacle as opposed to the traditional loop spectacles is that it is more representative of a straight metallic pin, which may resonate like a dipole under optimal conditions.

In order to test the hypothesis of increased SAR from semi-rimmed spectacles and other metallic objects, a new measurement system was first developed [7]. This involved modifying a SAM head so that it could be fixed face down in a DASY4 measurement system [8]. This allowed the electric field probe controlled by the robotic arm to scan the facial area. The standard twin phantom in the DASY4 prevented facial measurement because the head was sagittally bisected and laid on its side. Although this new design is not suitable for electric field measurements inside the nose, most other areas of the face can be accurately measured.

In the next stage, the optimum conditions for maximum SAR increase inside the head were sought by simplifying the spectacles to a straight pin and carrying out an analytical study [9]. It was found through simulations that pins ~0.45λ long positioned ~0.06λ away from the surface of the SAM phantom (located horizontally in front of the eyebrows) increased the 1g SAR by more than five times. Experimental verification with the Loughborough SAM showed an increase of seven times.

A sample of 14 semi-rimmed spectacles were tested on the SAM phantom [10]. These included both prescription glasses and sunglasses. Whilst all the spectacles had metallic frontal sections, some had metallic arms and some had plastic arms. In all cases, the spectacles reduced the 1g SAR in the head in the region directly behind the spectacles. This indicated none of the tested spectacles resonated at 900MHz. It was found that metallic arms influence the resonant length of the spectacles and those with plastic arms were too long to resonate at 900MHz. Simulations with a digitised version of one of the plastic-armed spectacles showed resonance at 660MHz, increasing the 1g SAR by approximately seven times.

In this paper, the authors investigate the effects of children's semi-rimmed spectacles on SAR inside the head, using both DASY4 measurements and simulations. Adult spectacles are also studied with and without their arms. Finally, adult spectacle lengths are shortened to identify the possibility of resonance at 900MHz.

II. Description of spectacles

Six semi-rimmed spectacles were investigated in this study; three children's spectacles (S1 to S3), two adult prescription spectacles (S4 and S5) and one adult sunglass (S6). The spectacles are shown in Figure 1 and are labelled S1 to S6.

978-1-4244-2721-5/09/$25.00 ©2009 IEEE


S1

S2

S3

S4

S5

S6

Figure 1 - Spectacles under test

The length of the metallic frames were measured from hinge to hinge following the contoured shape of the spectacles using thin solder wire. From repeat length measurements, the authors estimate the length measurements have an error margin of ±2mm. Table I gives the lengths in millimetres and as fractions of the 900MHz wavelength.

TABLE I - SPECTACLE LENGTHS FROM HINGE TO HINGE

Spectacle Name	Length (mm)	Length (wavelengths)
S1	145	0.43
S2	150	0.45
S3	161	0.48
S4	181	0.54
S5	186	0.56
S6	171	0.51

III. DASY4 MEASUREMENT SYSTEM

The development, testing and verification of the Loughborough SAM head used in this study is detailed in [7]. A CW 900MHz dipole source is used to represent a PDA type MCE held in front of the face. The specific choice of type of source is less critical in this scenario as it is held at a distance from the head and not touching the head as is the case when a MCE is held next to the ear. The dipole is placed underneath the head as shown in Figure 2. Its centre is at a perpendicular distance of 80mm from the tip of the nose. It is aligned horizontally in an ear-to-ear orientation directly below the eyebrows, which is 54mm from the tip of the nose.

Figure 2 - DASY4 Measurement setup

Spectacles were positioned on the SAM head such that the majority of the upper part of the metallic frames were in front of the eyebrows in the same plane as the dipole below. Placement accuracy was increased by using an alignment laser and plumb lines. None of the tested spectacles had plastic arms, although this type of design was clearly possible. Therefore, two sets of measurements were taken for each of the six spectacles. Following the first set of standard measurements, the metallic arms were removed to replicate plastic arms and the measurements repeated. When the arms were removed, the spectacles were attached to the SAM phantom using fine cotton thread.

IV. DESCRIPTION OF SIMULATIONS

SAR simulations were carried out using IMST's EMPIRE XCcel™ 5.20 [11]. The SAM phantom head was imported with a shell thickness of 2mm. The shell was assigned a relative permittivity of 3.5 and was lossless. The tissue simulating liquid inside the shell had a relative permittivity of 41.5 and a conductivity of 0.97S/m.

The spectacles were scanned on a flat-bed scanner along with a ruler at three orthogonal angles. The three sets of images were then discretised into 2mm squares. A 3D model was then constructed for use in the simulation tool EMPIRE XCcel™. The spectacle frames were classed as perfect electrical conductors. The lenses were simulated as CR-39 plastic with a relative permittivity of 2.24 and a loss of 0.001. Figure 3 shows the SAM head with spectacle S6 positioned in front of the face. The dipole is 80mm from the tip of the nose in the X direction and 54mm from the tip of the nose in the Z direction.

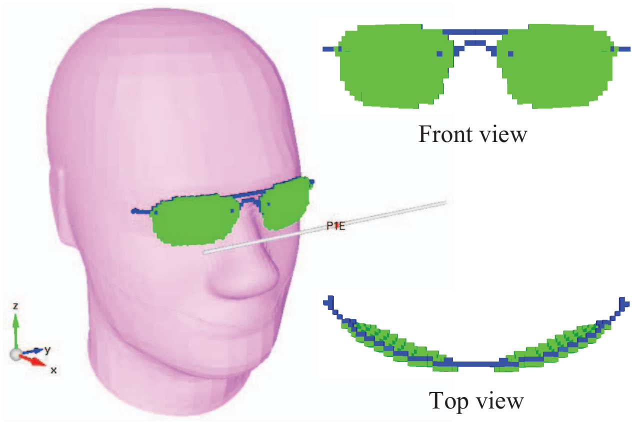

Figure 3 - Simulation model of the SAM head with S6 positioned in front of the face. Front and top view of S6.

V. Results

All measured and simulated spatially averaged 1g SAR results are normalised to 1W accepted power by the antenna. Initially a base measurement was taken for the 1g SAR without spectacles. This was recorded as 0.31 W/kg. Simulations using the SAM phantom indicated that the location of the maximum 1g SAR (0.38W/kg) was in the lower part of the nose, offset to one side. Due to the steep sides in the nose, the DASY4 was unable to measure the SAR in this region and so all measurements were taken in the region between the top of the nose and the top of the forehead. The simulated result examining only this region provided a 1g SAR of 0.30W/kg, which compared favourably to the measured value of 0.31W/kg. Figure 4 shows the 1g SAR values for the spectacles measured with and without arms.

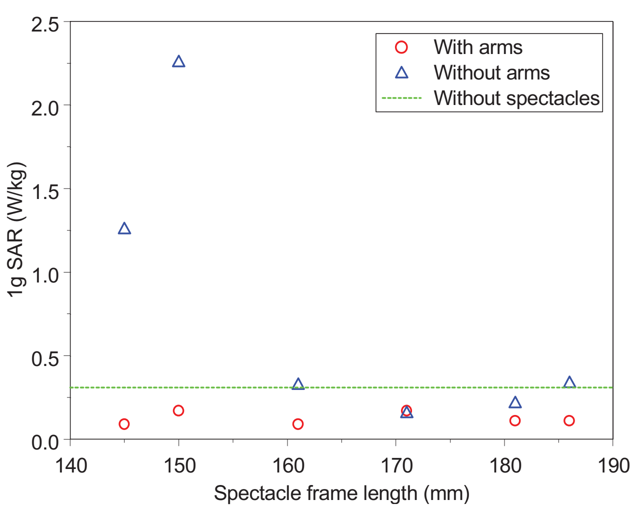

Figure 4 - Measured 1g SAR in SAM head at 900MHz six spectacles with and without arms

As with the results in [10], in all measurements, the spectacles with arms reduced the 1g SAR behind the eyebrows. In all cases, the maximum 1g SAR location measured was further towards the top of the head in the centre of the forehead region. Simulations of spectacles with arms showed that the maximum 1g SAR remained unchanged from 0.38W/kg and the location remained inside the nose. When the nose region was ignored in the simulation, the 1g SAR was reduced and its cube location moved further up the forehead as found in the measurements. It therefore appears that the extra length provided by the spectacle arms cause a shielding effect, reducing the energy absorbed behind the eyebrows.

Once the arms were removed, spectacles that were approximately 0.45λ long increased the 1g SAR between the eyebrows indicating a resonance of the frame. Spectacle S2 which had a length of 0.45λ, increased the 1g from 0.31 to 2.26W/kg compared to the measurement without spectacles. This is an increase of seven times. Spectacle S1 which was 0.43λ long also increased the 1g SAR when measured without arms. Spectacles that were longer than 0.45λ caused only minor changes in the 1g SAR when the arms were removed.

Measured 1g SAR values for all the spectacles without arms are presented in Table II along with their corresponding simulated values. There is good agreement between measured and simulated results providing confidence in the method by which the 3D spectacle models were constructed.

Table II - Measured and Simulated 1g SAR for Armless Spectacles

Spectacle Name	Measured 1g SAR (W/kg)	Simulated 1g SAR (W/kg)
No Spectacles	0.31	0.30
S1	1.26	1.25
S2	2.26	2.06
S3	0.33	0.36
S4	0.22	0.21
S5	0.34	0.26
S6	0.16	0.14

Further simulations and measurements have highlighted the sensitivity of the 1g SAR to the separation distance between the head and the spectacles. This sensitivity was also observed in the previous study [9] where it was shown that maximum coupling from the resonant metallic pin occurred when placed approximately 0.06λ from the surface. At 900MHz, this corresponds to about 20mm which is unrealistic for a pair of spectacles. For each spectacle, when carrying out 1g SAR measurements with and without arms, it was ensured that the separation distance between the spectacle's centre and the SAM head was kept constant. However, due to the different shapes of the spectacles, it was not possible to ensure the same separation distance for all spectacles. In all measurements, the separation distances between the spectacles' centres and the SAM phantom were in the 4mm to 8mm range.

1g SAR values greater than 1W/kg were demonstrated for S1 (145mm) and S2 (150mm) which were children's spectacles. In order to establish that this type of resonance near 150mm was not unique to those two spectacles, the adult spectacles S4, S5 and S6 were shortened to 150mm and remeasured. These results are shown in Table III.

TABLE III - MEASURED AND SIMULATED 1G SAR VALUES FOR SPECTACLES SHORTENED TO 150MM AND 148MM

Spectacle Name	Measured 1g SAR for 150mm (W/kg)	Measured 1g SAR for 148mm (W/kg)
S4	0.59	1.05
S5	0.81	1.38
S6	0.23	0.33

As can be seen, the increased 1g SAR values for spectacles shortened to 150mm are still relatively small compared to those achieved with S1 (1.21W/kg) and S2 (2.10W/kg). These results could be explained by the following reasoning. The dielectric loading effect of the head causes the straight pin to have an optimum resonance when 150mm long. Due to the head's curvature, the dielectric loading at the centre of the pin is expected to be higher than at the ends. All measured spectacles are curved to fit the front of the face, some more so than others (see Figure 3). Since more of the metallic structure is now closer to the head, the authors expect the dielectric loading to be higher and thus the frame to appear electrically longer.

This hypothesis was tested using a 150mm long 0.5mm diameter copper wire that was curved to follow the natural shape of the SAM head. The centre of the wire was 8mm from the surface of the phantom. SAR measurements were repeated with the DASY4, each time shortening both ends of the wire in situ. Measured results showed that a curved wire 137mm long can increase the 1g SAR to 1.54W/kg.

Spectacles S2 and S3 were the least curved, where as S6 was highly curved. S1, S4 and S5 were slightly more curved than S2 and S3. As shown in Table III, further shortening of S4 and S5 to 148mm increased the 1g SAR to above 1W/kg. This was expected because of S4 and S5's extra curvature compared to S2.

As spectacle S6 had a high level of curvature and did not resonate as strongly as S4 and S5 at 148mm, it was further shortened to ~140mm and remeasured. At this length, the measured 1g SAR was 1.34W/kg. Considering at its original length (170mm), the measured 1g SAR was 0.16W/kg, the shortening increased the 1g SAR by more than eight times. The frame length of 140mm is very similar to the curved wire length of 137mm used to produce a 1g SAR of 1.54W/kg.

VI. CONCLUSIONS

Metallic semi-rimmed spectacles that have a hinge to hinge length of approximately 0.45λ can increase the energy absorbed in the head. Compared to without spectacles, a resonant spectacle can increase the 1g SAR by a factor of seven. Longer and shorter spectacle lengths only cause minor increases. Due to their small size, this type of spectacle is most likely to be worn by children. The inclusion of metallic arms appear to detune the resonance away from 900MHz. Most adult spectacles appear not to resonate at 900MHz, with or without arms. Shortened spectacles have increased the 1g SAR indicating that the presence of extra metallic structures, such as nose pads, do not influence the resonance. It has been confirmed that highly curved spectacles resonate at shorter physical lengths due to the increased dielectric loading by the head.

These results represent the worst case scenario since the polarization of the E-field was perfectly aligned to the metallic frames. In normal MCE usage in the wider population, the radiation source is likely to be further away from the face. The children's spectacles have been tested on the standard SAM phantom whereas children's heads are smaller in size. The SAM phantom and liquid are also designed to give a conservative value for the SAR. The results provided here are also normalized to 1W accepted power where as in GSM the $1/8^{th}$ duty cycle applies.

Future work would involve scaling the SAM head to a size more representative of children and carrying out simulations with the children's spectacles. Simulations can also be carried out on heterogeneous head models of children. Spectacles coming into contact with the skin may change their effective lengths, which could impact on their resonant frequency.

REFERENCES

[1] IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3kHz to 300GHz, Standard C95.1-2005.

[2] ICNIRP 1998 Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300GHz), *Health Physics*, Vol. 74, pp. 494-522.

[3] J. Cooper and V. Hombach, "Increase in specific absorption rate in humans from implantations" *Electronic Letters,* Vol. 32, pp. 2217-2219, 1996.

[4] J. Fayos-Fernandes, C. Arranz-Faz, A. Martinez-Gonzalez, and D. Sanchez-Hernandez, "Effect of pierced metallic objects on SAR distributions at 900MHz" *Bioelectromag.*, Vol. 27, pp. 337-353, 2006.

[5] W. G. Whittow, C. J. Panagamuwa, R. M. Edwards and J. C. Vardaxoglou, "The Energy Absorbed in the Human Head Due to Ring-Type Jewellery and Face-Illuminating Mobile Phones Using a Dipole and a Realistic Source", *IEEE Trans. Ant. & Prop.*, Vol. 56, No. 12, pp. 3812 – 3817, 2008

[6] S. E. Troulis, N. E. Evans, W.G. Scanlon and G. Trombino, "Influence of wire-framed spectacles on specific absorption rate within human head for 450 MHz personal radio handsets" *Electronics Letters*, Vol. 39, pp. 1679-1680, 2003.

[7] C. J. Panagamuwa, W. G. Whittow, R. M. Edwards, and J. C. Vardaxoglou, "Experimental verification of a modified specific anthropomorphic mannequin (SAM) head used for SAR measurements" *2007 Loughborough Ant. & Prop. Conf.,* UK, pp. 261-264, 2007.

[8] Schmid & Partner Engineering AG, DASY4 Manual v4.1, March 2003.

[9] C. J. Panagamuwa, W. G. Whittow, R. M. Edwards, and J. C. Vardaxoglou, "A Study of the Effects of Metallic Pins on SAR using a Specific Anthropomorphic Mannequin (SAM) Head Phantom" *European Conf. on Ant. & Prop.*, Edinburgh, 2007.

[10] O. Ojerinde, C. J. Panagamuwa, W. G. Whittow, and R. M. Edwards, "SAR variations in the face due to semi-rimmed spectacles and polarized sources at GSM900 and GSM1800" *European Conf. on Ant. & Prop.,* Berlin, pp. 2962 – 2966, 2009.

[11] EMPIRE XCcel™ Manual, © IMST GmbH, November 2008