

On the question of whether to model or measure the levels of RF energy from mobile phones into the head

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Introduction: Seemingly a recent phenomena in fact the first commercial mobile phones were put into place almost sixty years ago by AT&T and South-western Bell. This first deployment on the 17th June 1946 took place in Saint Louis, Missouri and consisted of in-vehicle radio-telephones operating at 150 MHz with 60 KHz channel spacing. The system was a unidirectional paging service with a downlink to six channels and was delivered from a 250 kW transmitter atop the headquarters Bell in Pine Street.

However, it is only over the past ten years that handheld mobile communications devices have become more common than hats. Associated with this rise in popularity have been three significant trends. Firstly the devices have moved closer to the head so that now mobile phones are used tight against the ear or close to the front of the face Secondly, when after a short time the device was disconnected from the power supply of a vehicle and became truly portable, the energy stored with the device has tended to rise. Thirdly the frequency of excitation has tended to increase. The first and second of these trends conclude to the fact that the head is now routinely exposed to comparatively high field strengths and the third to the fact that radio frequency energy is now physically suited geometrically to coupling with structures found on and in the human body.

We state to begin with that energy rates from mobile phones are currently thought to be too low to cause damage to humans through heating.

It is accepted that radio frequency radiation (RFR) delivered at high enough rates can cause damage to human tissue. Such damage is due to thermal effects which can be defined as biological effects that occur when over time the RFR delivers enough energy to manifest a biological effect from the heat that it generates in the tissue. It turns out that RFR interacts with the molecules of the matter causing them to oscillate. In the head the most marked effects take place in the water. This is because the water molecules are themselves polar and have their own internal electric field. Friction between the water molecules gives up energy to the surrounding media in the form of heat thereby resulting in an increase in temperature. If the RFR frequency and the natural frequency of oscillation of the molecules is close or the same the heat generation is at its highest. Unfortunately, as a consequence of the advantages gained via propagation and the way our radio spectrum is occupied, mobile phone frequencies have tended toward better and better interaction with humans.

Undoubtedly mobile phones are incredible useful and are thus popular. The topic of whether or not energy from a mobile phone can harm humans is therefore a popular debate. We concern ourselves here with the question of how to evaluate the levels of RFR arriving in the head.

We begin by discounting the most obvious method for study namely invasive measurement of live humans and animals. The main problem here is that to measure the RFR (inside for example a human head), a probe is required which itself by its very presence will damage the surrounding tissue. However, it is the ethical issue of causing damage to living persons (and more so now animals), that tends to make such measurements unlikely. Measurements on corpses have similar issues. It is also debateable how useful such measurements would be. This is because there is a great diversity in humans, the shape and size of their heads, the layout within their heads and the

position and type of mobile device that they might use. These points have resulted in this seemingly intuitively fruitful methodology being discounted.

Non-invasive studies of humans and animals have yielded some important and interesting results. Such studies have tended to expose test subjects to doses of varying levels whilst recording parameters such as longevity, sleep and other behaviours against benchmark figures. Tests of this sort have for the most part been conducted on animals with short life spans.

Epidemiological studies have also been undertaken but these types of studies are known to have problems demonstrating negatives with effects that have low risks (for example RFR is not a health risk)ⁱ.

For now the two most popular methods adopted by the community are those of simulation and standardised measurement. The property for measurement is SAR^{iv}.

The rest of this paper is presented as follows. Section A contains some results from our work in FDTD simulation. In particular results are shown for the effects of using spectacles on SAR in the eye from communications enabled personal data assistants. In Section B we present discussion of techniques for measurement using a DASY4 robot measurement system.

Section A SAR in the Human Eye with Spectacles and PDAs

A head matrix provided by Brooks Air forceⁱⁱ was used. The head, which is based on MRI data, is that of an adult male and has twenty-five tissue types.

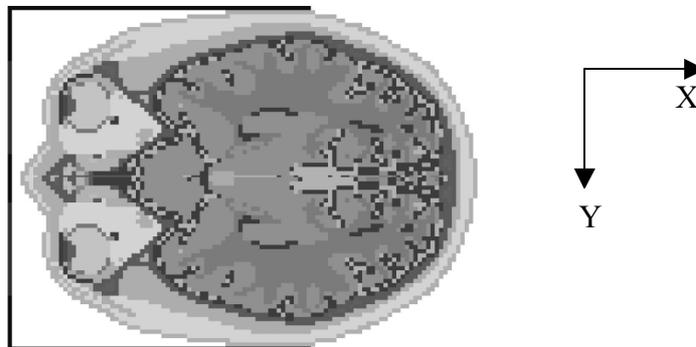


Fig. 1. A cross section through the eyes of the heterogeneous head. Spectacles have been added 2.6cm in front of the eye.

Fig. 1 below shows a cross section of the head including the spectacles through the centre of the eye. 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 head model has closed eyelids and the results in this paper are calculated with the eyelids closed. Fig. 1 also gives an indication of the complexity and resolution of the model.

Resolution for the head was of 2mm. Hence a cubic Yee cell with side of length 2mm is used. 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. The use of symmetry was found to have negligible effect on SAR results in the eye. At the interface between two materials, the average

values of conductivity and permittivity are used. Four arbitrary but representative 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 Fig. 2 for orientation and geometry.

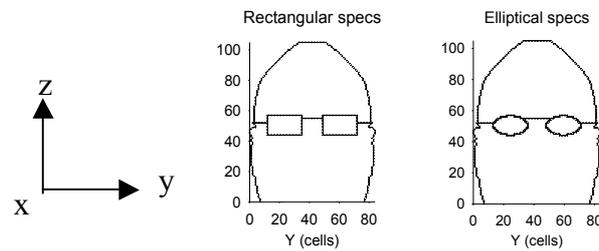


Fig. 2. The Orientation and coordinate system used. Rectangular and elliptical are shown relative to the outline of the head.

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 realistic Perspex lens 2mm thick. In addition to these basic geometric shapes, a nosepiece and a strut to the arm were included - see Fig. 2. 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.

To examine the effect of adding metallic spectacles the SAR SAR1G averaged over one gram of tissue was investigated. To represent the energy form the PDA a 50W/m² Ez polarized plane wave travelling towards the back of the head was used.

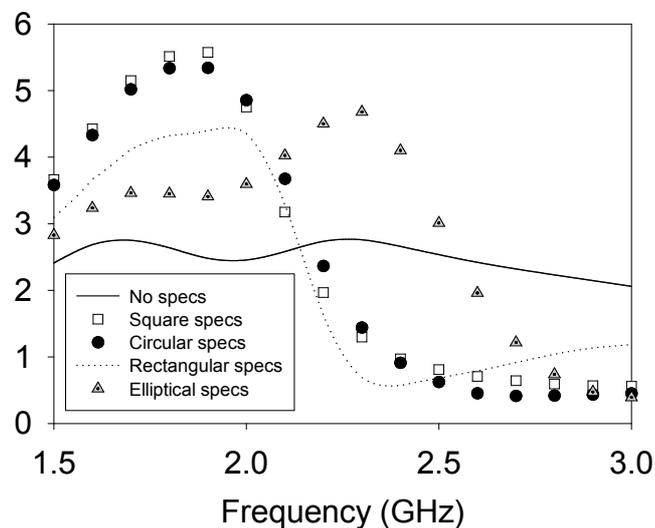


Fig. 3. The maximum SAR averaged over 1g in the eye.

The maximum SAR1G, see Fig. 3, is comparable with the ANSI/IEEE standards of 1.6/Kgⁱⁱⁱ. Metallic spectacles increase the SAR1G below 2.2GHz and decrease it above this frequency. Elliptical spectacles again cause a peak at a slightly higher frequency.

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 3.0GHz reduce the power absorbed in the eye by approximately 80%. A more complete discussion of these phenomena can be seen in the full paper^{IV}.

Section B Measurements of SAR to the face.

As has been mentioned on page one, invasive measurements of live humans are difficult to obtain since there are problems both physical and ethical involved in dipping a probe into the head. In addition no two of us are the same and we all use our mobile devices in different ways. Ideally we would need a volunteer with average brain size, head size and composition and have him use an average mobile phone in an average way. The results from these tests could then be used as a scaling factor that after a suitable safety margin was added could be applied as regulation for the manufacture of communications devices. It turns out that this has been partially achieved using a measurement system comprising of a phantom human head filled with specially formulated liquid; a robot arm fitted with a probe that dips into the head and a mobile phone powered to its maximum capability.

The phantom has a thin shell and is made of glass fibre. It is the size of an average male adult head (based on American military personal) and has thinner than normal ears to best represent people with thin ears or ears crushed to the head by a mobile phone. The system used in our measurements was a DASY4^V. The programme of research currently underway has the intention to produce results for comparison between FDTD simulations and measurements. Typically the mechanical arm of the robot has to take its measurements with its probe almost normal to the surface of the phantom. In the DASY4 systems this is facilitated by using only a left or right side of a head filled with solution. Whilst this is satisfactory for devices held to the ear the geometry is not suited to systems in which the device was held in front of the face. To measure this we require a phantom with the back of the head open rather than the midline or in some cases the top. In figure 4 we see the results of chopping away the rear of the head.

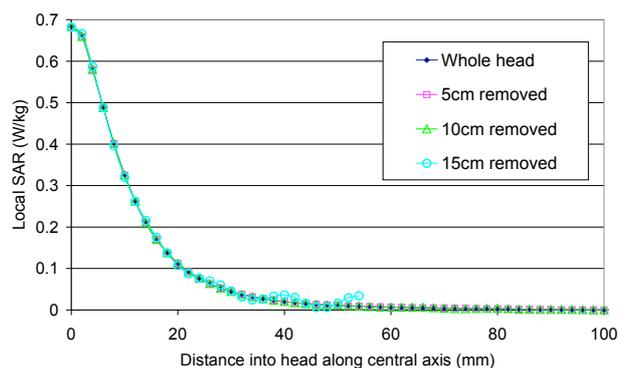


Figure 4 – Simulated local SAR for homogeneous SAM head when different length sections are removed from the back of the head

The figure 4 shows that at 1.8GHz, 10cm may be removed from the back of the head without a significantly change in Local SAR. The proposed cut point is shown below and lies conveniently behind the ears.

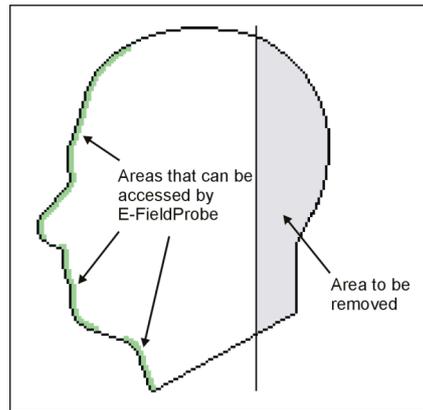


Figure 4 Right side view SAM head showing areas that can be accessed by the E-Field probe when the head is cut 6cm from the back

Simulations were (ongoing) carried out using both in-house FDTD code and SPEAG's SEMCAD-X^{vi} to determine the effects of removing different amounts of the head from the back. Simulations show that when this section of the head is removed, the 1g and 10g SAR values deviate by about +0.3% from the values obtained with the full head.

Section C Conclusions

Having illuminated the topic of discussion by an illustrative case study we are now in a position to discuss the relative merits of these two particular solutions.

Simulations can have complex electronic phantoms (EF) to work with. For example the FDTD simulation used here has 21 tissue types. This allows resonance properties to be seen clearly. Dispersion can be studied. At certain frequencies eyes will resonate. Once the initial coding is complete changes to the EF are cheap and can be made quickly and as computers improve quicker still. The proper conductivities can be simulated for example; the conductivity of skin is known and can be added to the ET. Simulated measurements of SAR can be made easily at any place in the head. The converse is not true of measurements.

Measurements systems can have real sources; for example your own mobile phone could be tested within minutes. They are also highly standardised so that proper comparisons can be made throughout the industry. In general people tend to have more confidence in measurements which is important since the fear of harm may itself be considered harm. The material boundaries within the head are continuous and have no staircase effects. The converse is not true of simulations.

In summary you will see that for a rigorous evaluation both are needed.

ⁱ Ahlbom A. Axelson O. Stotrup H.H., "Interpretation of Negative Studies in Occupational Epidemiology." Scandinavian Journal of Work, Environment and Health 1990,16:153-157

ⁱⁱ Brooks-Airforce. ftp://starview.brooks.af.mil/EMF/dosimetry_models/.

ⁱⁱⁱ C95.1-1992, A.I.S., IEEE standard for safety levels with respect to human exposure to radio frequency fields 3kHz to 300GHz. 1992.

^{iv} W.G. Whittow and R.M Edwards, "A study of changes to specific absorption rates in the human eye close to perfectly conducting spectacles within the radio frequency range 1.5 to 3.0GHz", IEEE Transactions on Antennas and Propagation, vol. 52, no. 12 pp. 3207-3212, 2004

^v Schmid & Partner Engineering AG, DASY4 Manual v4.1, March 2003

^{vi} Schmid & Partner Engineering AG, SEMCAD-X Reference Manual, December 2005