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Applications of a Genetic Algorithm for Identification of Maxima in Specific Absorption Rates in the Human Eye Close to Perfectly Conducting Spectacles

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Abstract—**this paper investigates relative changes in specific absorption rates due to perturbing metallic spectacles in proximity to the face. A representative electrical property biological matter model with twenty-five distinct tissue types based on images of an adult male is used with the FDTD method. Both plane wave and dipole source stimuli are investigated and are used to represent a mobile cellular enabled personal digital assistant held in front of the face. Results show that metallic spectacles may significantly alter SAR level distributions within the head. The frequency range investigated is 1.5 to 3.0GHz. Specific attention is given to energy interactions with the eyes. Results are given for several common spectacle frame shapes as well as whole head energy absorption comparisons. Whole head and single mirrored half head sensitivity data are also presented. A Pareto Ranked Genetic Algorithm (GA) is used to search for the spectacles that cause the highest and lowest SAR in the eye.**

***Index Terms*—FDTD, SAR, eye, metallic spectacles, PDA**

1. INTRODUCTION

The study of interactions between biological material and the energy generated by personal communications devices is currently topical. This paper investigates the field perturbation effects of radio-enabled personal digital assistants (PDAs) due to thin wire spectacles of various common shapes with simple slab lenses. A CW source is used to simulate a communications enabled PDA positioned in front of the head, (possible effects of a wire or a Bluetooth link to an earpiece have not been considered in this work). A rigorous Finite-Difference Time-Domain (FDTD) model is used. In previous works [1-4] it has been demonstrated that metallic spectacles can alter the specific absorption rate in the head and in particularly in the eyes. In recent years some work has been written up regarding mobile phones positioned near the ear [5-8]. Illumination has been considered from in front of the eye using realistic mobile phone models [7-9]. 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 [10, 11] and have previously found resonance in the eyes within typical cellular spectra. Bernardi [12] considered the eyes to be particularly sensitive organs due to their proximity to the surface of the head and their relatively low levels of blood flow when compared to other regions of the body. Dimbylow [7] also stressed the vulnerability of the eyes as having a tendency to accumulate damage and cellular debris. The lens is susceptible to cataract formation if there is a temperature rise of 3°C [13]. Lin [14] reviewed the possibility of cataract formation and showed that the temperature increases were too small to cause cataracts under normal conditions. The Stewart Report [15] includes a brief summary of experimental studies into RF effects on the eye and Elder produced a more detailed analysis [16]. They reported that pulsed RF fields at 2.45GHz, at moderate SAR levels, produced harmful effects in primates including lesions in the corneal endothelium and increased vascular leakage from the blood vessels of the iris. The threshold for these effects was dramatically reduced when the primates were pre-treated with ophthalmic drug timolol maleate. In the same area Cooper [17], modelled a geometric head, and Bernardi [18] 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 [19] 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 the SAR in that matter. Spectacles have received limited attention in the literature, however Bernardi [12] did model a glass lens in 2D. Troulis [4] 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. Griffin [1] performed measurements with a phantom and metallic spectacles and showed that spectacles can increase or decrease the level of radiation near the eyes by up to 20dB due to shielding, enhancement and depolarisation effects. Anderson [2] also 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%.

The novel area of head, thin wire spectacle and RF energy interaction from in front of the eyes will now be considered in greater detail.

2. DESCRIPTION OF MODEL

An independent 3D FDTD code has been written; see Taflove [20] for an excellent reference. Perfectly Matched Layers (PML), with geometric grading [21], absorbing boundary conditions are used to terminate the grid. The conductivity of each cell in the PML increases with the ratio 2.55, and the reflectivity at normal incidence is 0.00008%. 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.

2.1 Plane Wave Source Irradiation

A plane wave is injected into the grid using the total field / scattered field approach [20]. 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 source is a sinusoidal CW excitation. The power density used was 50W/m², the maximum permissible exposure limit for controlled environments [22, 23]. This is the power density used in a closely related paper by Hirata [11]. Note that the maximum permissible exposure limit for the general public is 10W/m² [22], and results in this paper can be scaled accordingly.

2.2 Dipole Wave Source Irradiation

For comparison a simple half-wavelength dipole model [20] has also been included in this paper. The dipole is vertically polarised fed at its centre with a sinusoidal CW source. The tangential E-field components are set to zero along the length of the dipole.

2.3 The Head Model

A head matrix provided by Brooks Air Force [24] was used. The head, which is based on x rays, CT scans, MRI data and photographs, is that of an adult male and has twenty-five tissue types. The tissues represented are listed, in order of decreasing volume in the head, in Table I. Figure 1 shows a cross section of the head including the spectacles through the centre of the eye, giving 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 was used. The lowest number of cells per wavelength was always greater than six, and reasonable results have been obtained with only four [10]. A line of symmetry, in the XZ 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 [11, 25], and thus assuming the other half of the head is identical. N.B. Figure 1 shows the whole head and Figure 6 has been mirrored to aid visualisation of the problem. The use of symmetry was found to have negligible effect on SAR results [26]. The effects of symmetry on the SAR in the eye are shown in Figure 2. The head is excited from the front with a 50W/m² Ez plane wave. The Brooks head is not symmetric as demonstrated by the left eye having a different average SAR from the right one. In this paper only the right eye (as seen from the front has been modelled). There is little change in the average SAR in this eye when the whole head is modelled. Note that when the symmetrical head is excited with a dipole in this paper, the infinity thin dipole is positioned at the centre of the head and therefore is orientated along the line of symmetry.

Figure 1 shows the layers of skin, fat and muscle tissues that make up the eyelids. To investigate the effects of the eyelid these layers of tissue were replaced with air in an elliptical region of 30mm by 12mm in front of the eye. It should be noted that the eyelid was removed and was not opened, as would be the case in a real human. Hirata showed [11] that opening the eyelid increased the average SAR in the eye by 15% at 5.0GHz. Bernardi [27] showed that the modelling of the eyelids is far more important at higher frequencies. At an excitation frequency of 30GHz, Bernardi showed that the SAR in the eye increased by a factor of five and the SAR in the lens increased by a factor of fifty, when the eyelids were opened. The results of opening (removing) the eyelid, in the frequency range 0.5 to 4.5GHz are shown in Figure 3. Note that the number of cells per wavelength at 4.5GHz is always greater than four, which provides reasonably accurate results [10]. The figure shows that the average SAR in the eye is more dependent on the frequency of excitation than on the presence of the eyelid. Between 1.0 and 2.4GHz opening the eyelid decreases the average SAR in the eye, as the eyelid provides a better matching between the air and the eye and hence less energy is reflected back at the interface. At frequencies above 2.5GHz the average SAR in the eye is increased when the eyelid is removed. Therefore, in the frequency range, 1.5 to 3.0GHz, the worst case scenario, with the highest SAR in the eye, is likely to be with the eyelid kept shut. Removing the eyelids is not a simple task and is arbitrary to some extent. There are many parameters such as the thickness of the tissue, the size of the eyelids and how open the eyelids are, which make repeating the procedure very difficult. Removing the eyelid is difficult, but opening the eyelids to model a real scenario is even more prone to error. For these reasons the eyelid will be kept shut throughout this paper.

The dielectric properties are calculated with aid of the 4-Cole-Cole extrapolation [28] and are frequency dependent. 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 [29]. Example dielectric properties for 1.8GHz are listed in Table I.

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

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

Where E_i is the magnitude of the electric field in the tissue, 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 [30].

3. MODELLING THE SPECTACLES

The spectacles were modelled using metallic Yee cells, by setting the conductivity of the cells equal to the conductivity of copper. Nikita [31] and Bernardi [18] both used this technique to model metal shapes. Four arbitrary but representative frame types were researched: square (external dimensions of 36mm x 36mm in Y and Z axis), rectangular (48mm x 28mm), elliptical (48mm x 28mm) and circular (external diameter of 44mm). See Figure 1 for orientation and geometry.

In each case the centre of the lens was positioned at the centre of the eye in the YZ plane, and 26mm 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 140mm in the X direction, touching the head above the ear.

The FDTD, code including the PML absorbing boundary conditions, has been validated with results by Meier [32]. Figure 4 shows the SAR as a function of distance into a 3 layered sphere excited by a 0.45λ dipole at 1.8GHz. The head had a diameter of 200mm, composed of skin (5mm thick), skull (10mm thick) and brain. The head was positioned 15mm away from the dipole. A cell size of 2.5mm was used for this comparison.

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The results show good agreement. In previous works [3] the average SAR in an anatomical head excited with Ez and Ey polarised plane waves as a function of frequency also showed good agreement with Hirata [11].

4. RESULTS

To examine the effect of adding metallic spectacles, two metrics were investigated; the SAR_{1g} averaged over one gram and the average SAR in the eye. The results in sections 4.1 to 4.3 have been made with a 50W/m² Ez polarised plane wave travelling towards the back of the head.

4.1 Maximum SAR In The Eye Averaged Over 1g

The maximum SAR_{1g}, see Figure 5, is comparable with the ANSI/IEEE standards of 8.0W/kg for controlled environments [23]. The SAR_{1g} is calculated according to Caputa [30] using only eye tissues and no air is included in the 1g cube. Metallic spectacles significantly increase the SAR_{1g} below 2.2GHz and decrease it above this frequency. Elliptical spectacles cause a peak at a slightly higher frequency. The different shapes and sizes of spectacles produce different effects.

4.2 Average SAR In The Eye

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}. Hence the graph of average SAR in the eye is not shown to save space. The eye in this model has a mass of approximately 8.37g and is comparable to the ICNIRP safety standard of 10W/kg averaged over 10g for controlled environments [22].

The maximum effect of metallic spectacles was with square frames at 1.9GHz, which resulted 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%.

All four frames examined increased or decreased (depending on the frequency) the power absorbed in the whole head by approximately 10%. The maximum increase in the power absorbed in the head was with square frames at 1.9GHz, which resulted in an increase of approximately 13%.

Figure 6 represents the difference that square spectacles make to the SAR at 1.9GHz and shows 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.

Note that Hirata [25] found an increased average SAR in the eye, when the incident plane wave was from an oblique angle to the left or right of the head. However the enhancement due to metallic spectacles is much larger than the variation due to the angle of incidence. Further work will investigate a head with metallic spectacles excited from an oblique angle.

4.3 Using A Pareto Ranked Genetic Algorithm With An Ez Polarised Plane Wave Stimulus

A Genetic Algorithm (GA) was used to search for the maximum effects of adding metallic spectacles at 1.8GHz. Two texts on Genetic Algorithms are [33, 34] The aim of the GA was to provide the complete range of SAR that are produced in the eye with the many shapes and sizes of real spectacles. The algorithm used was that described in [35]. The search algorithm had two objectives; the average SAR in the eye and the maximum SAR averaged over 1g of the eye. Seven different genes were varied to create chromosomes representing various different spectacles; the genes are shown in Table 2.

The search space was thus represented as having 51840 discrete points. The GA was run with a population size of 80 of which the best 16 were kept and their genes were used for future generations. 20 generations of spectacles were used, but no significant change was seen in the Pareto set after 12 generations.

The GA found a configuration of spectacles with an average SAR in the eye of 3.399 W/kg, an increase of 159%. The same configuration of spectacles increased the maximum SAR averaged over 1g from 2.639W/kg to 7.286W/kg, an increase of 176%. The spectacles that gave the biggest increase in the SAR in the eye were positioned 26mm in front of the eye. The frames were rectangular with a width of 36mm and a height of 38mm. The lens was 4mm thick and made of glass. The strut length was 18mm.

The GA also produced configurations of spectacles that reduced the SAR in the eye. The lowest result found for the average SAR in the eye was 0.469W/kg, a decrease of 64% compared to without spectacles. The SAR_{1g} was 0.994W/kg. The spectacles were positioned 28mm from the eye. The frames were rectangular, 46mm wide by 38mm high. A 6mm glass lens was used and the strut length was 6mm.

To investigate the effects of the different parameters that describe a pair of spectacles, individual parameters were examined separately. The spectacles were initially the same as the ones that gave the highest SAR in the eye as described above and then the individual parameters were varied. Only the SAR averaged over the whole eye will be considered as the maximum SAR_{1g} is always approximately twice the average SAR over the whole eye. It should be noted that the following graphs only show the relationship based on the spectacles with the highest SAR in the eye and are not a general rule.

Figure 7 shows that the SAR in the eye is at a maximum when the frames are 26mm away from the eye. Note that the spectacles could not be moved closer than 24mm from the front of the eye without the frames lying inside the head. As the distance increases above 26mm, the SAR in the eye decreases.

Figure 8 and Figure 9 show the average SAR in the eye as a function of the size of the frames for rectangular and elliptical spectacles respectively. Figure 8 shows that for narrow rectangular frames, the average SAR in the eye increases with the height of the frames. However the effect of wider frames is less dependent on height. 46mm wide frames were not found to significantly increase the average SAR in the eye regardless of the height of the frames. Figure 9 shows that for elliptical frames the average SAR in the eye increases as the height of the frames increases. Comparing the two graphs also shows that for the original configuration of spectacles, rectangular frames give higher SAR in the eye than elliptical frames.

The effects of varying the lens are shown Figure 10. This graph also shows the metallic spectacles with no lens (thickness 0mm). The addition of the lens increases the SAR in the eye. Generally the SAR in the eye increases with the thickness of the lens. Results are slightly higher with a glass lens as opposed to a Perspex lens. The lens acts as an adaptor as described by Bernardi [12]. The different lens configurations give variations of up to 15% to the average SAR in the eye. As the strut length is varied, the total width of the spectacles changes. As the strut length increases the SAR in the eye increases by less than 2%. Decreasing the strut length means the arms become tapered to fit the head. Therefore neither the strut length or the tapering of the arms produces significant changes to the SAR in the eye.

Generally the average SAR in the eye was mainly influenced by the size of the frames, with high narrow spectacles likely to give the highest results. Rectangular frames gave higher SAR in the eye than elliptical frames at 1.8GHz.

To investigate the average effect of different metallic spectacles, one hundred pairs of spectacles were produced, with seven random parameters from the range in

Table **2** governing the seven genes. All of these spectacles increased the average SAR in the eye from 14 to 143%. The average increase was 56%. Rectangular frames had a slightly larger effect, increasing the SAR in the eye by 62% compared to 49% with elliptical frames. One hundred random spectacles were also modelled in the same way at 2.4GHz and 3.0GHz; increasing the SAR in the eye by 51% on average at 2.4GHz and decreasing it by 11% at 3.0GHz.

4.4 Using The GA With A 0.45λ Z-Directed Dipole At 1.8GHz

In this section the Ez plane wave excitation is replaced by Z-directed dipole positioned 8cm in front of the nose. The dipole was given an input power of 0.125W to allow comparison with a realistic source. The GA was applied with stimulus at 1.8GHz with the same parameters as in

Table **2**. The highest average SAR in the eye found by the GA was 0.057W/kg, an increase of 167% compared to a head without spectacles excited with a dipole. The spectacles can be described with the following parameters; frames - eye distance=28mm, width=36mm, height=38mm, 6mm glass lens, rectangular frames with a strut length of 14mm. These spectacles are the same size, shape and have the same lens material as the pair that the GA found for the Ez polarised plane wave excitation. The differences between the two pairs of spectacles are small differences to the distance from the lens to the eye, the lens thickness and the strut length. The small variations in these three parameters are less significant than the size and shape of the lens as shown in figures 7 to 10. The similarity of the spectacles found by the GA shows that spectacles behave similarly with a Z-directed dipole and a Z polarised plane wave. It also suggests the GA is converging as it finds very similar spectacles with two different excitations.

Figure 11 shows the average SAR in the eye for the Z-directed dipole with the spectacles that gave the highest SAR in the eye with an Ez polarised plane wave. Figure 11 also shows the head excited with the Ez plane wave with the same spectacles to allow comparison. It should be noted that the results from the plane wave excitation have been scaled by 1/60 so the amplitudes are comparable. The scaled results are very similar for the two excitations over the frequency range 1.5 to 3.0GHz. The same spectacles give an increase in the average SAR in the eye of approximately 160% at 1.8GHz and a decrease of approximately 80% at 2.4GHz.

4.5 Using The GA With An Ey Polarised Plane Wave At 1.8GHz

In this section the head is rotated so that it is excited with an Ey polarised plane wave from the front travelling in the X direction. The power density was kept at 50W/m². The GA was again used to search for the highest average SAR in the eye and the maximum SAR_{1g} in the eye, with the same genes as outlined in Table **2**. The GA found no spectacles that increased the SAR in the eye. The maximum average SAR in the eye found was 0.836W/kg, which corresponds to a decrease of 45%, compared to the same excitation with a head without spectacles. This pair of spectacles were positioned 32mm in front of the eye, had a rectangular frame of 48mm by 38mm, a 6mm glass lens and the strut length was 16mm. Varying the properties of the spectacles was found to be less significant than with an Ez polarised plane wave. Varying the strut length caused variations in the average SAR in the eye of 10%, compared to 2% with an Ez plane wave.

Figure 12 shows the spectacles outlined in the paragraph above over the frequency range 1.5 to 3.0GHz. The same spectacles have also been modelled with a 0.125W Y-orientated 0.45λ dipole, 8 cm in front of the nose. As a horizontal dipole could not be modelled using symmetry, the whole head model was used in conjunction with the dipole to allow comparison with the horizontally polarised plane wave excitation. Again the Y-orientated dipole and Ey plane wave excitations give similar results with and without spectacles across the frequency range considered, if the results are scaled. At all frequencies considered this pair of spectacles reduced the average SAR in the eye.

Hirata [11] showed that horizontal and vertically polarised plane waves incident on a human head without spectacles result in the head absorbing different amounts of energy. This is due to the head being taller than it is wide. However these effects are small compared to the variation of the SAR in the eye with metallic spectacles using the two different polarisations. Clearly this is due to the spectacles. The authors presume the horizontal nose piece and the struts to the arms become more significant with the horizontally polarised source, and therefore the spectacles are no longer a resonant object in the range of frequencies investigated.

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5. 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 3.0GHz, when the excitation is from the front. The SAR averaged over the eye has been shown to increase by up to 160% and decrease by up to 80%, depending on the specific spectacles and the frequency of excitation. An analysis of random spectacles indicated that an average pair of spectacles can be expected to increase the SAR in the eye by about 50% at 1.8 and 2.4GHz and marginally decrease it at 3.0GHz. Increases of around 10% are possible for the entire head. The differences between different spectacles 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 shown. A Genetic Algorithm has been used to find the spectacles that gave the highest and lowest SAR in the eye. Although metallic spectacles cause high SAR levels in the eye with a 50W/m² plane wave excitation, current safety standards are unlikely to be breached by a real source, as indicated by the SAR levels with a dipole excitation. The addition of spectacles was found to always decrease the SAR in the eye for both a horizontally polarised plane wave and a horizontally directed dipole. A dipole excitation gives similar results to the plane wave excitation, once the results have been scaled, showing that the effects of spectacles are more dependent on the size of the frames, the frequency and the polarisation than the specific source.

It is evident, that in the range of frequencies considered, natural frequency resonance is observable in the eyes only due to the vertical forcing functions of an Ez plane wave and a Z-directed dipole and that the spectacles cannot be considered in isolation. Rather the head and the spectacles should be considered as a system having several natural frequencies within the range of frequencies considered here. In terms of SAR increases, of less effect on the resonant mechanism are; the back of the head beyond 5 cm, the X-directed side arms of the spectacles and the Y-directed short sections of the spectacles. Lens thickness is important as well as the shape and size of the lens rim. For vertical forcing functions the authors have found that both a half and a whole pair of spectacles allow a natural frequency to occur in a lone eye of a full head. This allows some possible simplification of the resonant system under study. In general our experiments have shown that in the frequency range considered horizontally polarised stimulators give rise to lower rates of SAR in the eye for heads with spectacles.

The resonant mechanisms are therefore complex and are the subject of further work.

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Dr Rob M. Edwards read in Electronic Engineering with Communications at the University of Sheffield, England and studied for his PhD with the Department's Communications and Radar Group. He is the Director of the Centre for Mobile Communications Research (C4MCR) and is also a Lecturer in Mobile Communications.

Final author version. Science, Measurement and Technology, IEE Proceedings. Volume: 152 , Issue: 3. Pp 89 – 96, 2005.

7. SET OF TABLES WITH TITLES

Table 1. Dielectric properties at 1.8GHz and specific gravities.

Tissue	Conductivity (S/m)	Relative Permittivity	Density (kg/m^3)
Fat	0.078	5.349	920
Muscle	1.341	53.549	1050
Brain Grey Matter	1.391	50.079	1040
Brain White Matter	0.915	37.011	1040
Bone Cortical	0.275	11.781	1990
Tendon	1.201	44.251	1220
Skin (Dry)	1.185	38.872	1130
Bone Cancellous	0.588	19.343	1920
Mucous Membrane	1.232	43.850	1040
Bone Marrow	0.068	5.372	1040
Air (Internal)	0.000	1.000	0
CSF	2.924	67.200	1010
Cerebellum	1.709	46.114	1040
Gland	1.501	58.142	1050
Lymph	1.501	58.142	1040
Cartilage	1.287	40.215	1100
Blood Vessel	1.066	43.343	1040
Tooth	0.275	11.781	2160
Vitreous Humor	2.033	68.573	1010
Body Fluid	2.033	68.573	1010
Blood	2.044	59.372	1060
Nerve	0.843	30.867	1040
Eye Sclera	1.602	53.568	1030
Lens	1.147	45.353	1050
Cornea	1.858	52.768	1080

Table 2. The genes used with the Genetic Algorithm.

Gene	Range	No. of permutations
Distance from spectacles to eye	24 to 34mm, every 2mm	6
Width of spectacle frames	34 to 48mm, every 2mm	8
Height of spectacle frames	20 to 38mm, every 2mm	10
Lens material	Perspex, glass	2
Thickness of lens	2 to 6mm, every 2mm	3
Shape of spectacle frames	Rectangular, elliptical	2
Length of strut to arm	2 to 18mm, every 2mm	9

Final author version. Science, Measurement and Technology, IEE Proceedings. Volume: 152 , Issue: 3. Pp 89 – 96, 2005.

8. LIST OF CAPTIONS TO ILLUSTRATIONS

Figure 1. The orientation and geometry of the head and spectacles. A cross section is shown through the eyes in the XY plane. Square and circular geometric spectacles are also shown relative to the outline of the head in the YZ plane.

Figure 2. The effects of using a line of symmetry in the model to reduce computational time.

Figure 3. The effect of opening the eyelid of the Brooks head over the frequency range 0.5 to 4.5GHz.

Figure 4. The SAR into a 3 layered spherical head excited by a dipole at 1.8GHz, compared with Meier.

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

Figure 6. 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.

Figure 7. Varying the distance from the front of the eye to the spectacle frames of the spectacles that gave the highest average SAR in the eye at 1.8GHz.

Figure 8. Varying the size of rectangular frames of the spectacles that gave the highest SAR in the eye at 1.8GHz.

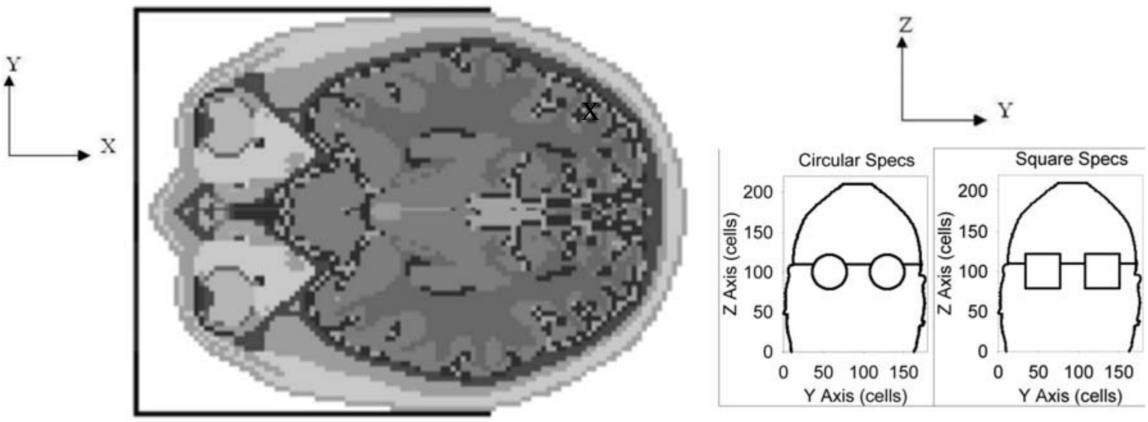
Figure 9. Varying the size of elliptical frames of the spectacles that gave highest average SAR in the eye at 1.8GHz.

Figure 10. Varying the lens of the spectacles that gave the highest average SAR in the eye. N.B. The points at 0mm, represent the case where no lens exists between the metal frames.

Figure 11. Using the spectacles that gave the highest average SAR in the eye at 1.8GHz for the Ez plane wave with two different excitations: Ez plane wave and a Z-directed dipole. N.B. the plane wave results have been scaled by a factor of 1/60.

Figure 12. Using the spectacles that gave the highest average SAR in the eye at 1.8GHz for the Ey plane wave with two different excitations: Ey plane wave and a Y-directed dipole. N.B. the plane wave results have been scaled by a factor of 1/60.

9. ILLUSTRATIONS



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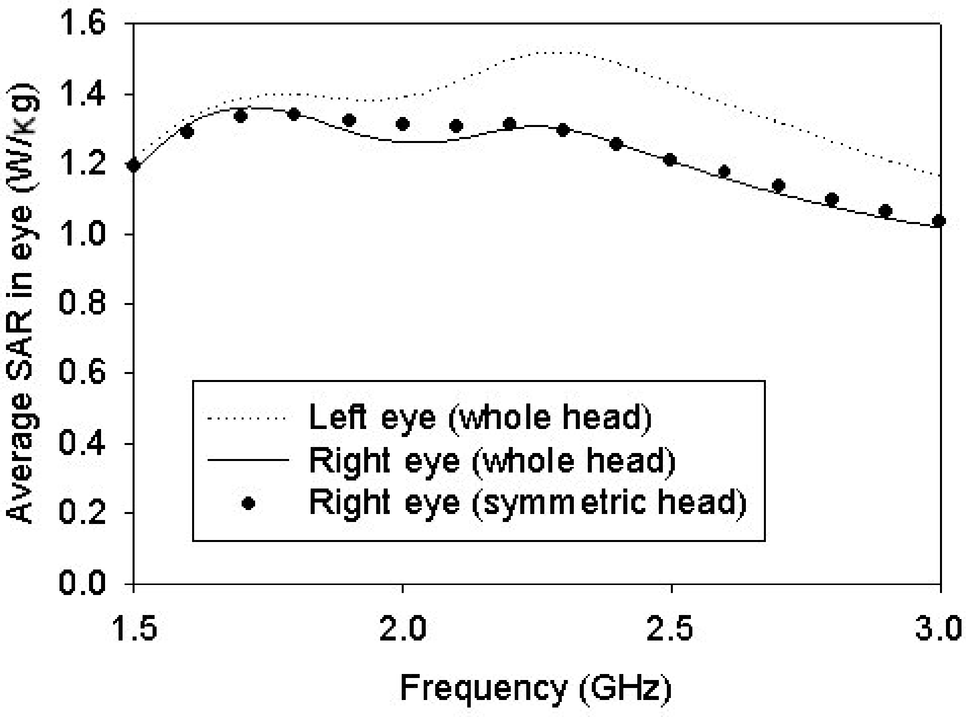

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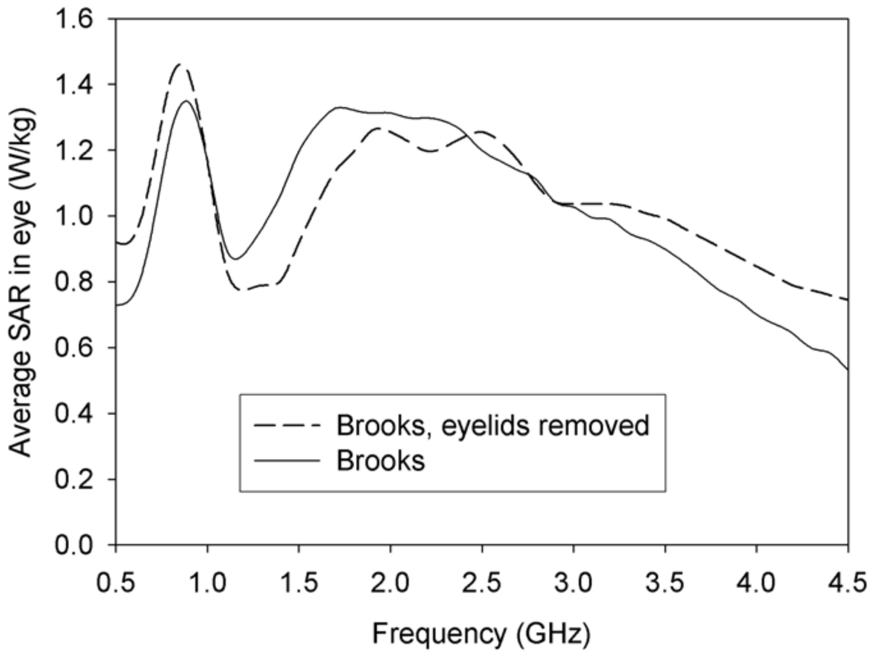

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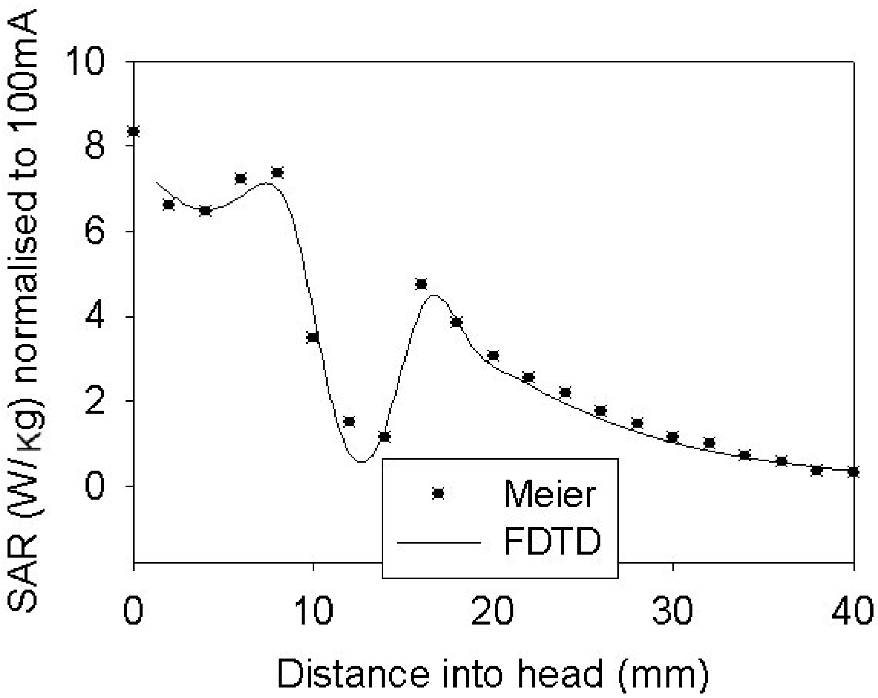

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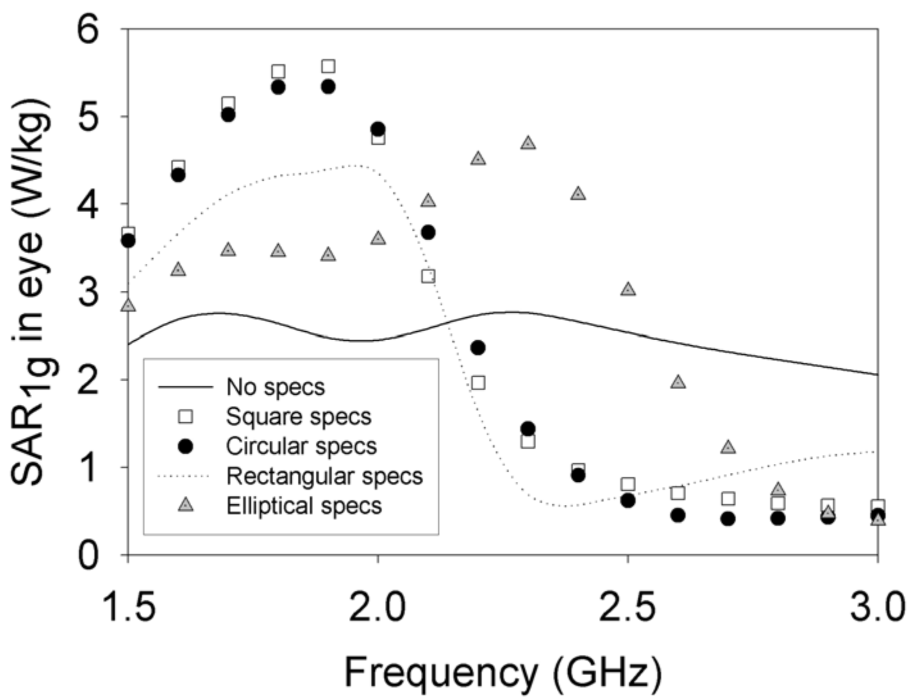

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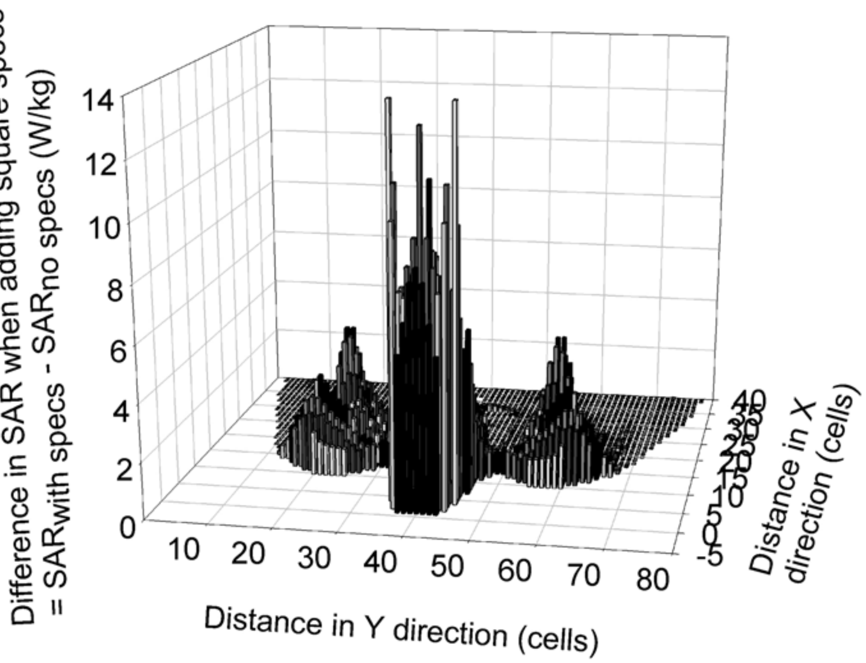

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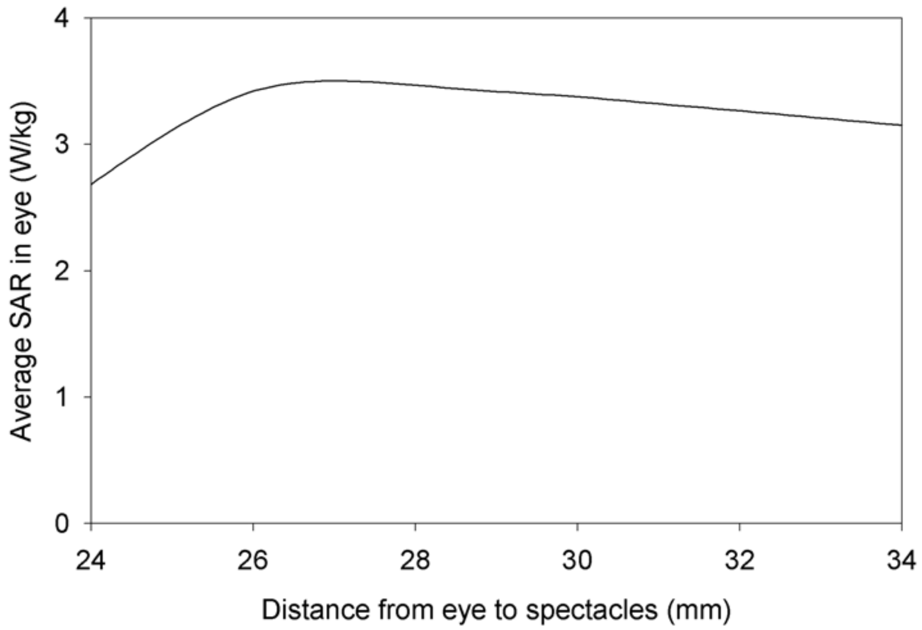

Figure 7. Varying the distance from the front of the eye to the spectacle frames of the spectacles that gave the highest average SAR in the eye at 1.8GHz.

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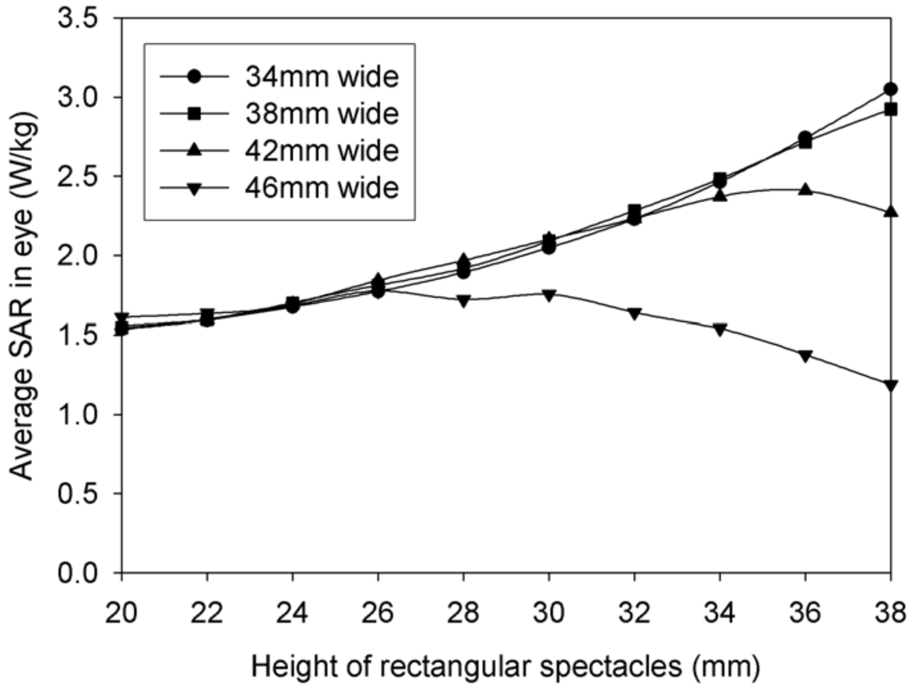

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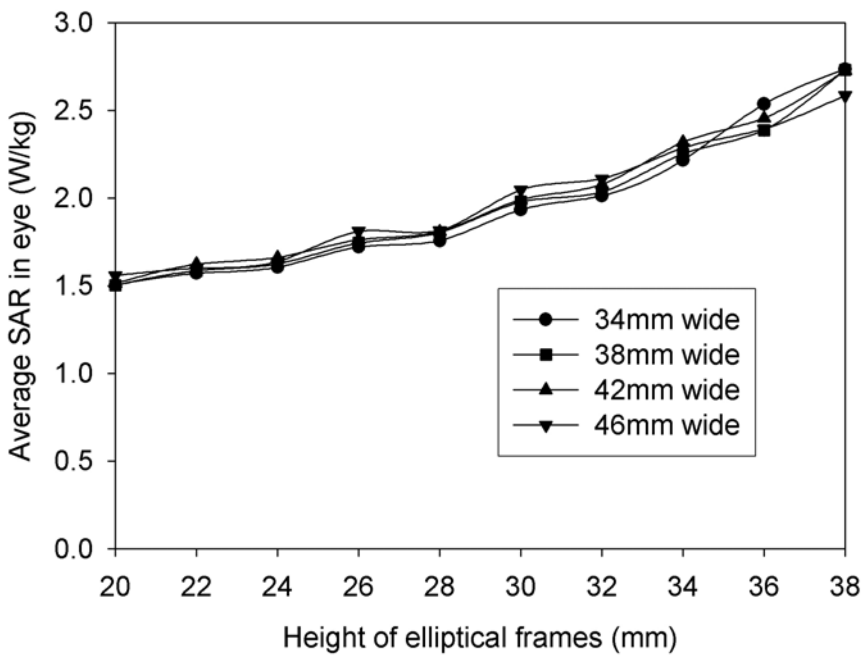

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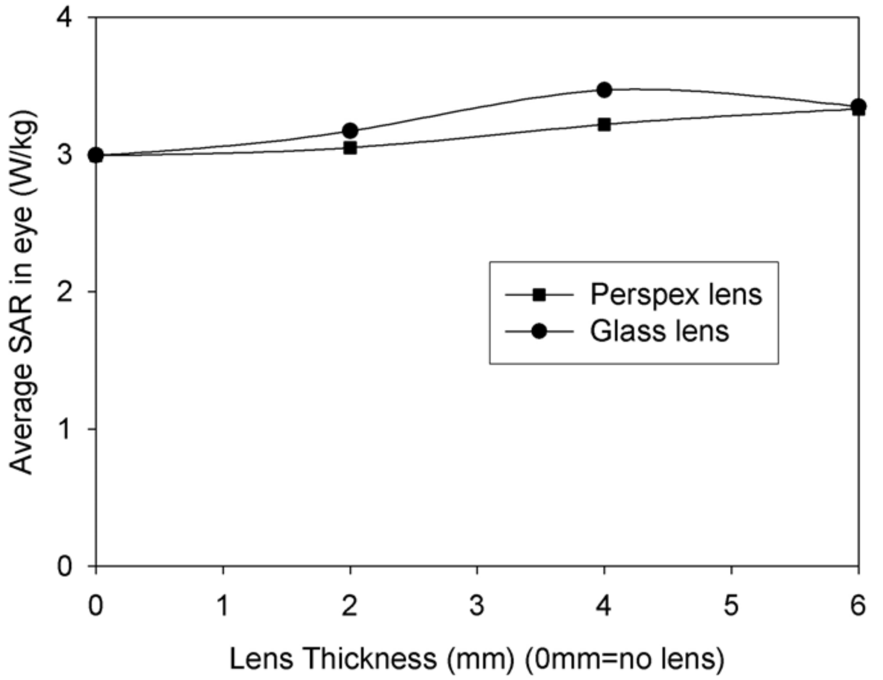

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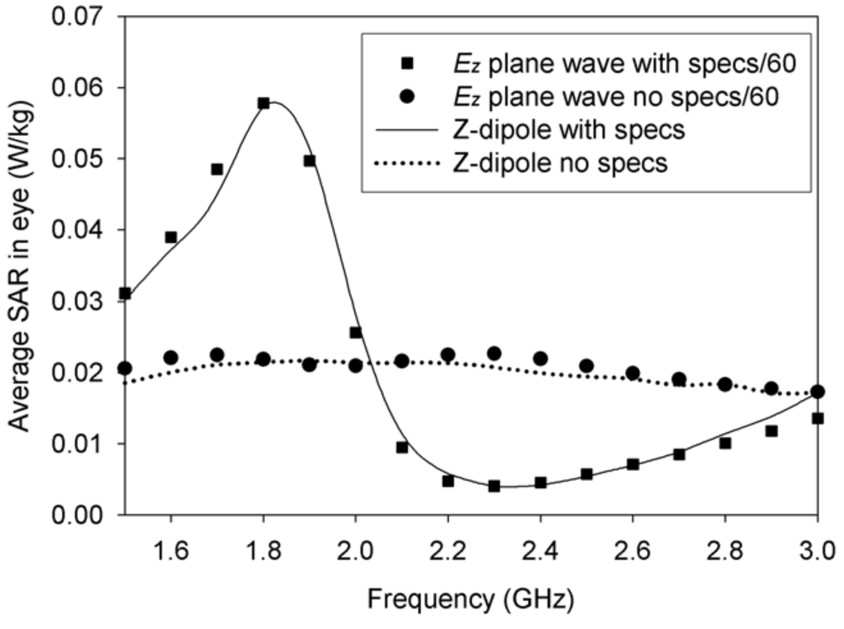

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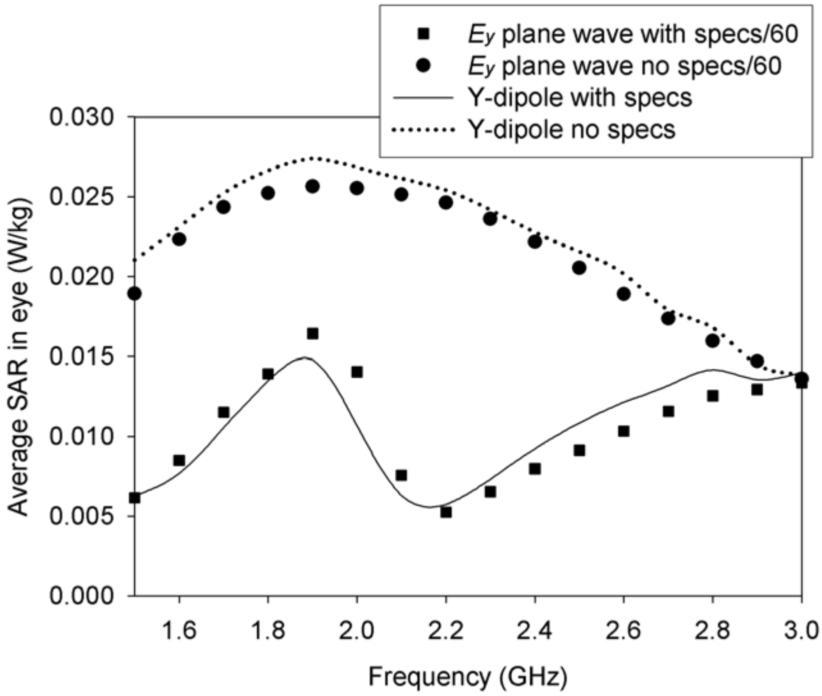

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