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RESEARCH ARTICLE

Evaluation of EMF Power Absorption in Human Eye Tissue

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Abstract

A deterministic mathematical method is adopted to evaluate the electromagnetic power absorbed by human eye tissue. Specific absorption rate (SAR) is calculated for a multilayer human eye mathematical model. The effect of electric field strengths ranging from 1V/m to 1kV/m is investigated for wide frequency spectra. Mathematical simulation, using recently reported frequency dependent electrical properties, is applied for three different models. The models investigate the exposure and absorption level of the eye lens. The frequency dependence of the SAR and the irradiance is illustrated for different electric field strengths. The present work investigates the microwave and low frequency range(100Hz-1GHz) effect on different eye tissue. Results are compared with recent international safety standards.

1. INTRODUCTION

The biological effect of the extensive employment of the electromagnetic waves in communication, among other applications; is a potent source of debates. The unprecedented spread of mobile networks and the progressively developments of Wi-Fi technologies warranted an equivalent alarm of the possible health hazard on humans, animals and even plants [1-7].This alarm is not limited to the effect of microwaves but also to the electric power lines of low frequency and high power. There are two basic hypothesis that tackle the possible biological interactions with EMF. Firstly, thermal effects which enjoy considerable theoretical interpretation. Secondly, non-thermal interaction is still subtle; showing inconsistent and inconclusive results. Thermal and non-thermal mechanisms of interaction of RF and microwave energy with different biological tissues and systems are discussed and investigated [8-14].

Almost all the reputable institutes have adopted the thermal effects argument and based their safety limits accordingly. These international safety standards are based mainly on the specific absorption rate, SAR, which is the power intensity absorbed by 1kg of specific organs.

The human eye is considered to be highly sensitive to EMF exposure. Its tissues, especially the lens, cannot stand excessive increase of temperature so special interest was given to possible effects of EMF on the visual organ. The SAR distribution in the human eye due to high-frequency EMF has been presented through analysis performed with numerical techniques using an accurate model of the eye developed from MRI image scans [15]. Specific absorption rate (SAR) and thermal effects were also determined under the exposure to microwaves [16].

In the present study, a deterministic mathematical simulation model that describes the human visual system is adopted. The cornea, humorous fluid, the lens and vitreous fluid are considered as a set of successive media subjected to normal incident EMF of different doses. Hence, the frequency dependence of the SAR in the human eye is evaluated. The main goal of the model is to compare the international safety standards with the actual mathematically calculated limits. The eye is considered as a successive layers of nonmagnetic-dielectric media. The irradiance and adsorbed power are calculated for each layer in frequency range (100Hz-100GHz). The results obtained are discussed in the light of the present data available.

2. METHODOLOGY

In the present work, we deal macroscopically with the problem of incident electromagnetic waves on a dissipative medium, namely eye tissue. The model introduced employs a cuboid, of the tissue under investigation, ofcross sectional area 1mm^{2}and thickness, Δx. The model is subjected to normal incidence of parallel polarized EM wave on one of its faces propagating in the x direction. Mathematical analysis is adopted to calculate the electric and magnetic field intensities incident on successive interfaces. A multilayer model is then introduced simulating a complete human eye considering theactual thickness of each layer in accordance with the human eyeanatomy. The incident field on a specific layer is that transmitted from the previous one. Reflection and transmission occurs at each interface following relations (3) and (4) below. The power density absorbed in each layer is calculated from the resultant electromagnetic wave produced. The electromagnetic parameters used are recent reported data for different eye tissues. Both transmitted power and that reflected at the opposite interface, form the absorbed power through a specific tissue layer. Fundamental properties defining how much is reflected, refracted and transmitted are the electrical and magnetic parameters of the medium, permittivity, $\varepsilon(f)$, conductivity, $\sigma(f)$, and permeability, $\mu(f)$. The parallel polarized electric and magnetic fields take the form:

$E_i(t,x)=E_0 sin(2\pi ft-kx)$ $\quad$ $H(t,x)=\sqrt{\mu(f)\varepsilon(f)}E_0 cos(2\pi ft-kx)$ (1)

where k is the wavenumber.

The electromagnetic power vector is represented as:$S(t,x)=E(t,x)\times H(t,x)$ (2)

For the ith layer:

$E_r(f,t)=r_{i+1}(f)E_0 e^{-\delta_i(f)\Delta xi/2} sin(2\pi ft+k_i x+\alpha_{i+1})$ (3)

$E_t(f,t)=t_i(f)E_0 e^{-\delta_i(f)\Delta x/2} sin(2\pi ft-k_i x+\alpha_i)$(4)

$E_{ti}(f,t)=E_{0ti} sin(2\pi ft+2k_i\Delta x_i+\alpha_{0i})$(5)

$E_{oti}(f,t)=E_{0i}\sqrt{r_{i+1}(f)^2+t_i(f)^2+2r_i(f)t_i(f)cos2k_i\Delta x_i}$ (6)

where $r_i(f)$,$t_i(f)$, and $\delta_i(f)$ are reflection, transmission and absorption coefficients respectively, of the ith layer, determined purely by the parameters of the two media.

The complex form of the permittivity is: $\varepsilon_i = \varepsilon_i^{'} + j\varepsilon_i^{''}$. For low values of the loss tangent of the medium, $tan\delta_i=\frac{2\pi f\varepsilon_i^{''}}{\sigma_i}$, one can easily neglect the loss component of the permittivity, $\varepsilon_i^{'}$, with respect to the storage component,$\varepsilon_i^{''}$. In other words, the medium is treated as a homogeneous dielectric with a dielectric constant,ε_i.

Hence, $r_i(f)=\frac{\sqrt{\varepsilon_i}-\sqrt{\varepsilon_{i+1}}}{\sqrt{\varepsilon_i}+\sqrt{\varepsilon_{i+1}}}$ $\quad$ $t_i(f)=\frac{2\sqrt{\varepsilon_i}}{\sqrt{\varepsilon_i}+\sqrt{\varepsilon_{i+1}}}$(7)

Irradiance is thus deduced as:

$I_i(t,x)=½\sqrt{\varepsilon_i(f)/\mu_i(f)}E_{0i}^2 sin(2.(2\pi ft-k_i x)$ (8)

Specific absorption rate, associated with electric field intensity, is expressed as:

$SAR_i(f,t)=\int_0^{\Delta xi}\frac{\sigma i(f)}{\rho i}E_{rmsi}^2(t,x)\,dx$ (9)

E_{rmsi} is the root mean squared value of the total electric field, $E_{ti}(f,t)$, inside the tissue which is the phasor sum of both transmitted, E_{ti}, and reflected,E_{ri+1}, components that constitute a phase difference of $2k_i\Delta x_i$.

3. RESULTS AND DISCUSSION

Specific biological tissues of the eye layers are assumed to be subjected to a normal incident electromagnetic plane wave. Each layer is considered homogeneous and investigated in accordance with the above mentioned model. Three cases are studied to illustrate the dependence of the specific absorption rate, SAR, and the incident electric field intensity, E_0, for a wide frequency spectrum. In addition to this, the SAR variation with the frequency is calculated and represented at specified electric field values. The mathematical model applied depends greatly on media parameters, referred to earlier. These parameters are produced using data averaged from Cole-Cole theory [17], electrode polarization and sensors as reported by [18-22].

3.1. Cortex Lens

The eye lens is assumed to be made of a single material identical to the lens cortex. The lens is assumed to be submerged in vitreous humor and subjected to normal EM wave. Figs 1a-1b illustrate the rise of SAR function, in log scale, versus the electric field for different frequencies. Due to the difference in scale the response is divided to express low and high frequency ranges. It is clear that the SAR varies with the electric field in a non linear increase leading to an asymptotic level that is highly dependent on the field frequency. These asymptotic levels for f>10MHZ exceed SAR of0.1mw/kg. This is true for field intensities less than 200V/m. The relationship between SAR and frequency at different field intensities is illustrated in Fig.1c. It is noteworthy that there are observed changes in the pattern at 1MHz and1GHz.

Log (SAR) Vs electric field, E, for the lens cortex for different frequency values

Fig. 1a

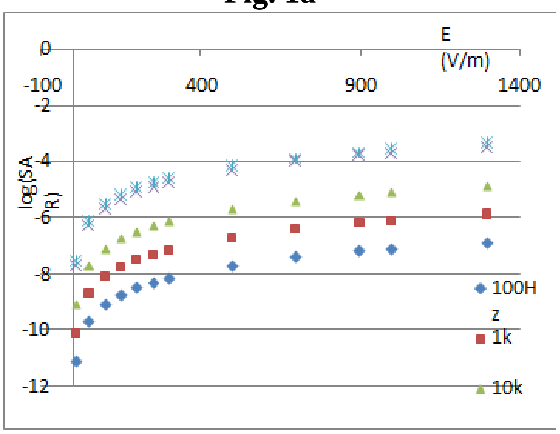


Fig. 1b

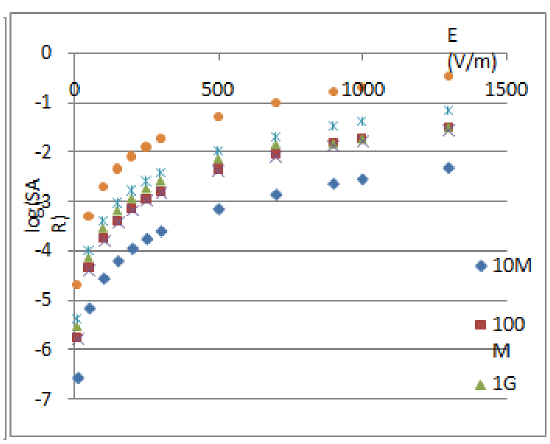
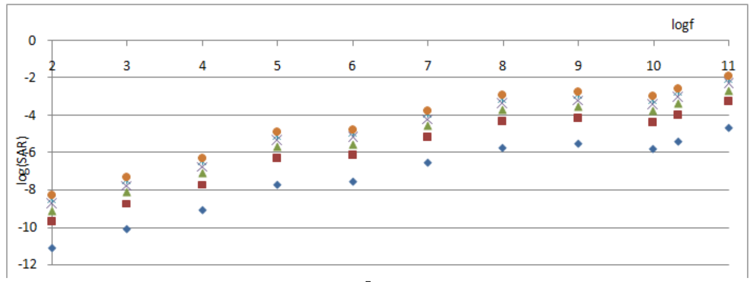


Fig. 1c

Log (SAR) Vs log(f) for the lens cortex calculated at different values of E_0



3.2 Cortex-Nucleus Lens

In this case the eye lens is considered a three layer of anterior cortex followed by nucleus then a posterior cortex layer. The whole multilayer lens body is treated mathematically as mentioned above. Figs 2a-2b-2c-2d illustrate the rise of SAR versus electric field of different frequencies. Whereas, Figs 3a-3b-3c, illustrate the rise of SAR versus frequency, for different electric field intensities. Irregular variation in the pattern is observed in the range 1MHz-1GHz except for the nucleus.

Log (SAR) Vs electric field, E, for the human eye lens model for a)100Hz b) 1kHz

Fig 2a

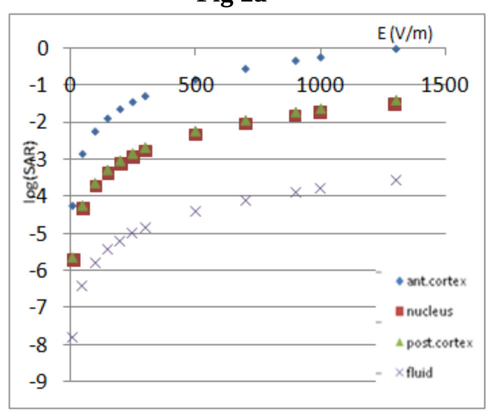
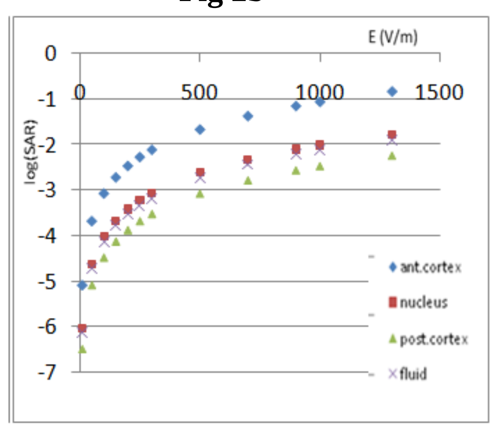


Fig 2b



Log (SAR) Vs electric field, E, for the human eye lens model for c)1MHz d) 1GHz

Fig 2c

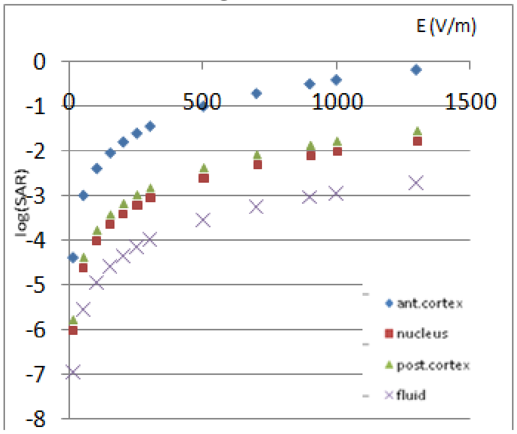
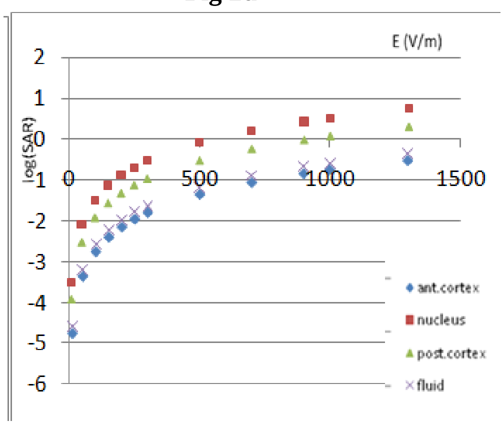


Fig 2d



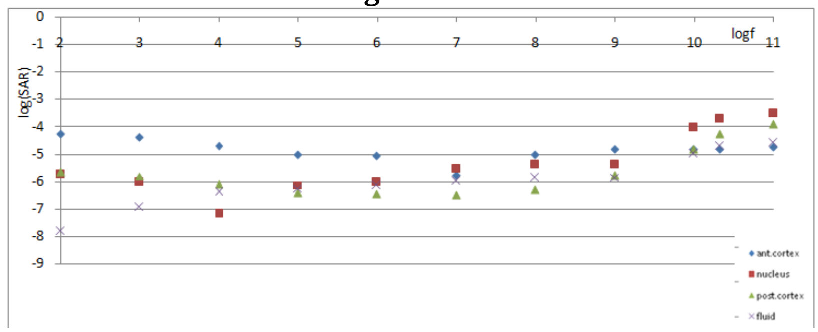
3.2 Whole Eye Model:

A multilayer model is mathematically constructed to simulate the incidence of a wide spectrum of electromagnetic radiation on the human eye.

Regarding the fact that the area of incidence of the wave is infinitesimal, planer representation of the surfaces is hence acceptable. The incident electromagnetic field on a specific layer is that transmitted from the previous one. Furthermore, the power absorbed in each layer is calculated inserting the electric field as the phasor sum of both transmitted field from the previous and that reflected on preceding interface. Figs 4a-4b-4c illustrate the SAR function versus frequency for field intensities of 0.1, 0.5, and1kV/m respectively. Irregularities are recognized at 10kHz,10MHz and 10GHz are apparently consistent.Figs 5a-5b, illustrate the irradiance versus frequency in log scale, for field intensities of 0.1 and1kV/m respectively. The dB power density consumption in each layer can be calculated as 20 log(I/I_0). Irregularities, recognizable at 1MHz and 1GHz, apparently coincide for both curves.

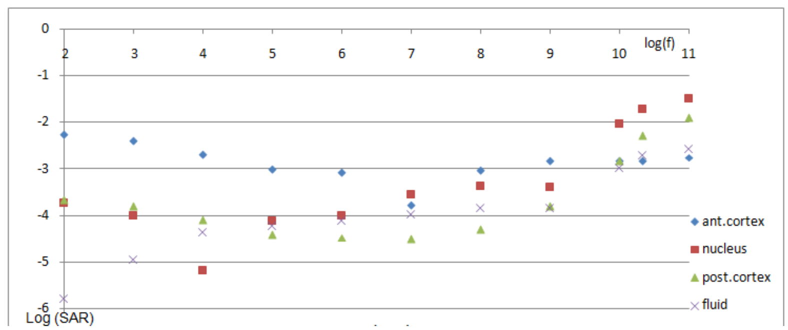
Log (SAR) Vs log(f) for the human eye lens model calculated at E_0=100V/m

Fig. 3a



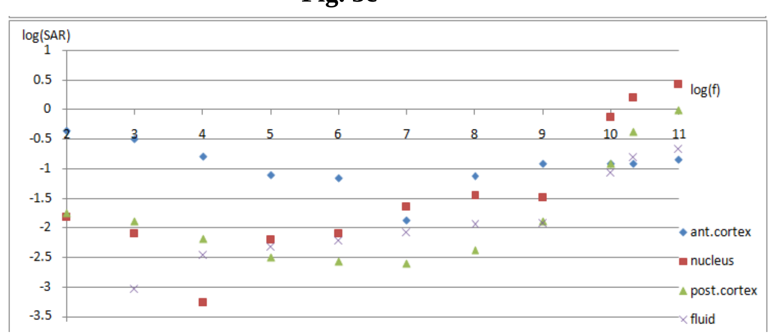
Log (SAR) Vs log(f) for the human eye lens model calculated at E_0=500V/m

Fig. 3b



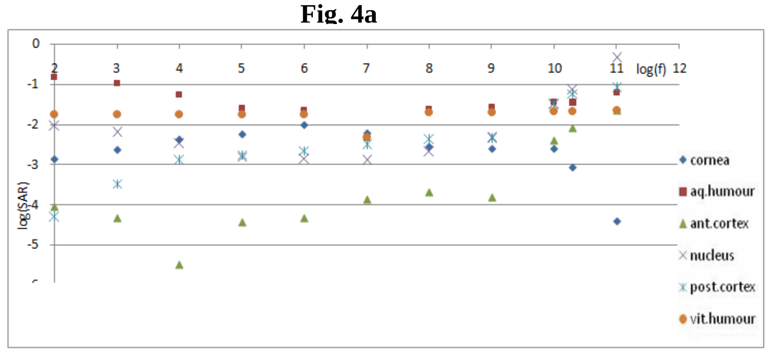
Log (SAR) Vs log(f) for the human eye lens model calculated at E_0=1kV/m

Fig. 3c

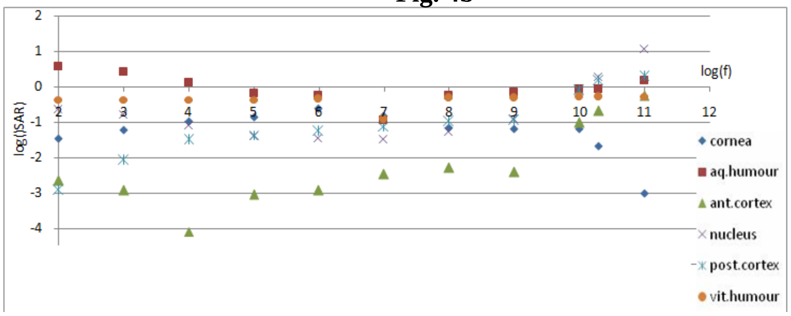


Log (SAR) Vs log(f) for the whole human eye model calculated at E_0=100V/m

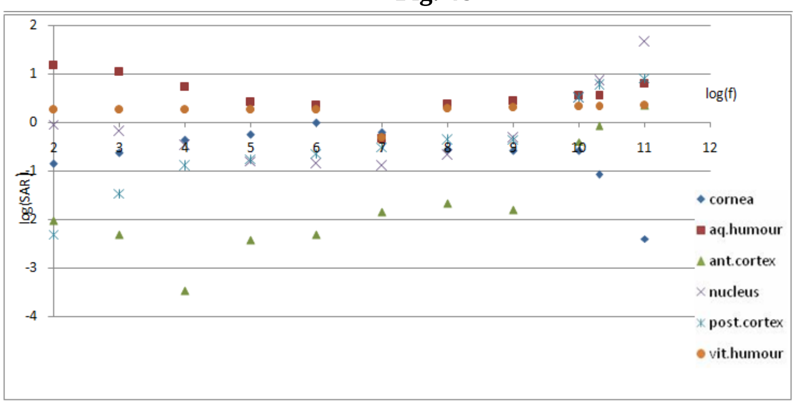
Fig. 4a



Log (SAR) Vs log(f) for the whole human eye model calculated at E_0=500V/m
Fig. 4b

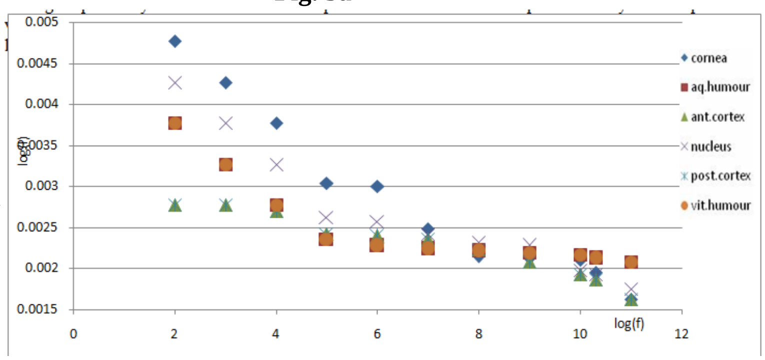


Log (SAR) Vs log(f) for the whole human eye model calculated at E_0=1kV/m
Fig. 4c

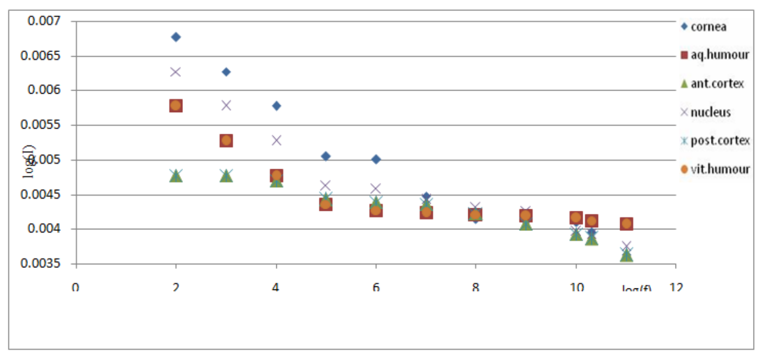


Despite the lack of evidence of biological effect of non-ionizing radiation, scientific communities periodically report safety standards for most frequency ranges. Many mechanisms of EM interaction with biological tissueare still not well known nor are relevant, health safety standards are widely approved by scientific communities. Research on RF energy has been conducted worldwide for many years by FDA and FCC who set policies and procedures for wireless phones [23]. IEEE, ICNIRP and WHO are renowned protection agencies that set SAR international standards for handheld wireless phones (not to exceed 0.04 W/kg), [24-28]. SAR measurement is averaged over (1g-10 g). The dimensions of the investigated model with mass density give masses that almost lie within the range. Harmonization of ICNIRP and IEEE C95, results show basic restrictions of adverse health effect threshold for whole and partial body exposures as shown in Table1 and Table2 standardized for occupational and public exposure respectively website at [29-34]. The IEEE latter organizations restrict the whole and partial body exposure to 0.4W/kg and 10 W/kg for occupational exposure respectively. Whereas, they restrict the whole and partial body public exposures to 0.08 W/kg and 2W/kg respectively. These values are compared to the results of the present study. In the present work, it is noteworthy that the trend of the curves representing the SAR distribution shows a non linear valley around a frequency of 10MHz which is persistent for most data.

Irradiance, log(I) Vs log(f) for the whole human eye model calculated at E_0=100V/m
Fig. 5a



Irradiance, log(I) Vs log(f) for the whole human eye model calculated at E_0=100V/m
Fig.5b



From the results obtained and considering the international safety limits, we conclude firstly that there is a strong link between the frequency and the electric field strength. Secondly, for certain frequency ranges the safety limits are exceeded.

Table 1
Occupational Exposure

Biological Tissue	Thickness mm	Whole Body(0.4W/kg)			PartialBody(10W/kg)		
		0.1 kV/m	0.5 kV/m	1 kV/m	0.1 kV/m	0.5 kV/m	1 kV/m
Cornea	0.449	------	f=1MHz	f>1MHz	-----	-----	----
Aqueous Humour	2.794	------	f>100Hz	f>100Hz	-----	-----	f<1KHz
Ant. Cortex	1.234	------	f>10GHz	f>10MHz	-----	-----	f>100GHz
Post. Cortex	2.4895						
Nucleus	1.2448	f>100GHz	f>100Hz	f>100Hz	-----	f>100GHz	f>100GHz
Vitreous Humour	15.8479	------	f>100Hz	f>100Hz	-----	-----	----

Table 2
Public Exposure

Biological Tissue	Whole Body(0.08W/kg)			Partial Body(2W/kg)		
	0.1 kV/m	0.5 kV/m	1 kV/m	0.1 kV/m	0.5 kV/m	1 kV/m
Cornea	------	10kHz<f<10 MHz	f<20GHz	----	-----	f>0.9MHz
Aqueous humour	f>1KHz	f>100Hz	f>100Hz	----	100Hz<f<1 0GHz &f=100GH z	100Hz<f<10 0GHz except f=10MHz
Cortex	------	f>10GHz	------	-----	f>20GHz	f>10GHz
Nucleus	f>100GHz	f>1GHz	f>100Hz	-----	f>20GHz	f>10GHz
Vitreous humour	------	f>100Hz	f>100Hz	-----	----	100Hz<f<10 0GHz except f=10MHz

4. CONCLUSION

Frequencies in the range from 1MHz to 1GHz , SAR values are below safety limits for all electric field intensities under consideration as shown in Tables 1 and 2. These tables exhibit correlation of the present data obtained for different eye layers with the international standards.

Taking into consideration the effects of both electric field intensities and the frequency, most of the data are within safety limits except for the nucleus which exceeds these limits at field intensity of 0.1kV/m and frequency higher than 1GHz. These results indicate that it is safe for wireless industry to concentrate their applications within these frequency ranges. Because it lacks vascular cooling facilities, the eye is the most sensitive organ to thermal effects induced by incident EMF. Accordingly this work provides a good and dependable safety measure to the other organs.

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