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Electromagnetic Modeling of the Human Eye for Wireless Environment

Dhara Patel, Ved Vyas Dwivedi and Y.P. Kosta

V.T. Patel Dept. of Electronics and Communication Engg.
Charotar University of Science and Technology Changa, Gujarat, India
E–mail: dhara_com06@yahoo.co.in , vvdwivedi.ec@ecchanga.ac.in,
ypkosta@gmail.com

Abstract

An eye is an important transceiver part and a wireless communication tool in human body and so needs to be studied when exposed to electromagnetic radio frequency signals. This research paper analyzes, discusses and presents an electromagnetic modeling of the human eye as a dielectric cavity resonator. Various numerical analysis-based and time domain simulation-based results obtained using a high frequency structure simulator are produced that includes return loss, transmittance, power consumption and thermal effects at desired frequencies. The known electrical and physical properties of human eye and that of dielectric resonator operating under similar technical conditions and assumptions are compared. The main biological substances, of which a human eye is composed of, are kept in dielectric circular waveguide for its dominant mode and the resonance is found through iterative simulations. All biological substances show the resonance property proving that no energy absorption taking place in human eye at particular frequencies whereas at other frequencies there is some level of power absorption. This study computes the specific absorption rate (SAR) and maximum temperature increase in the eye because of electromagnetic radio frequency fields generated by wireless terminals such as mobile phones. SAR and temperature-rise depend on the distance between eye and RF transceiver - the mobile phone and the angle between the line-of-sight and shortest normal path. We found that for 1.9 GHz, the maximum SAR value at 1.5cm distance is 8.39 W/kg and at 3.5 cm it is 3.34 W/kg and increased temperature value is 2.2 mK°/s and 571 µK°/s respectively. The effects of close interaction between the eye and waves are investigated and future perspectives are highlighted.

Keywords: Human eye, temperature, dielectric resonator (DR), Q-factor, mobile phone, High Frequency structure Simulator (HFSS)

Introduction

The human eye is one of the most sensitive tissues that get adversely affected and thermal damaged due to intense radiofrequency (RF) electromagnetic (EM) wave exposure [1]. Thus, it is interesting to investigate on the possible ocular effects that could occur when the eye falls in the direct line of propagation of the electromagnetic RF fields produced by the widely used handheld transmitters as mobile phones. The eye is particularly sensitive to heating because of lack of blood perfusion [2]. The human eye is accurately modeled by considering several ocular tissues, such as retina, lens, sclera, vitreous humor and cornea. These tissues are very important from a thermal point of view since they have significant values of the blood flow and metabolic rate [1]. The geometrical modeling of human eye is quite complicated as far its electromagnetic response to wireless RF signals is concerned. In this paper, the human eye is not modeled as a whole but the main tissue-parts are proved to be resonating at particular frequencies separately. Table I shows the internationally accepted safety standards Federal communications commission (FCC) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) which should be maintained [3].

Table I : Maximum temperature increases (ºc) in the lens temperature increases in the lens for the SAR table I values prescribed in the safely standard d=(i) 1.2cm(ii)3.2cm(iii)5cm(iv)15cm

Sr. No.	900MHz		1900MHz	
	ICNIRP	FCC	ICNIRP	FCC
I	0.348	0.160	0.332	0.143
II	0.334	0.175	0.309	0.159
III	0.333	0.183	0.309	0.150
IV	0.336	0.192	0.316	0.138

Table II : Different frequency providers with operating frequencies

Service Providers	**Freq. Range (MHz)**
Vodafone	935 – 941.4
Idea	941.4 – 947.8
BSNL	947.8 – 954.2
Airtel	1805 - 1811

In this paper, a comparison of human eye with a low cost, light weight, small size equivalent metallic cavity dielectric resonator is made which can be incorporated into microwave integrated circuits and coupled to planer transmission lines. The proposed human eye model is simulated in high frequency structure simulator (HFSS) version.10.0. Section II of this paper, explains the theory and standard approach and electrical parameters and the section III presents the analysis and modeling related issues wherein the simulation results are produced and discussed in section IV. The section V concludes the present work, and highlights the related future perspectives for the research aspirants.

Theory

Mobile service providers

Various wireless service providers operate at different standard frequencies enlisted in table II to which we are exposed in our daily routine very frequently. Our study assumes that the RF source (mobile phone) and the human eye are positioned face-to-face, as shown in figure 1.

Standard approach

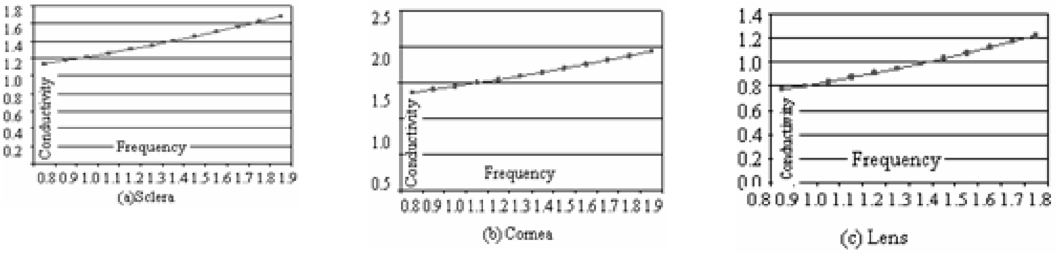
When the dielectric constant of the DR is over 30, the reflection coefficient (Γ) at the interface between DR body and the air becomes unity and most of the energy is reflected from the inner surface(s) of the DR [4] as expressed in (1).

$$\Gamma = \frac{\eta_0 - \eta}{\eta_0 + \eta} = \frac{\sqrt{\varepsilon_r} - 1}{\sqrt{\varepsilon_r} + 1} \to 1 \tag{1}$$

Where, η_0 is characteristics impedance of the air (~ 377 Ohm) and η is characteristics impedance of the dielectric material. When some reflections are in DR, the standing waves are formed and electromagnetic resonance occurs. The resonant frequency (f_r) of DR is depended on the resonance mode, the size of DR and dielectric constant(ε_r). In this paper, the dominant mode of the circular waveguide (TE_{11}) is considered. In order to reduce the diameter and height of DR, it is necessary to have high ε_r. A change in the f_r is the result of a change in physical dimension and operating conditions. The quality (Q) factor known as frequency selectivity in an application has inverse proportion with the loss tangent (tan σ) of the material. For high frequency applications, higher Q is needed.

Electrical parameters

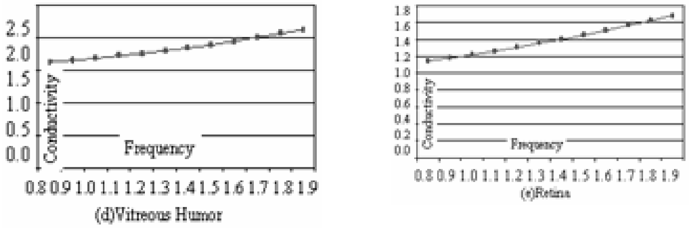
Exposure of EM waves has increased maximum conductivity of vitreous humor and minimum conductivity of lens which is clearly depicted in figure 3. Figure 4 shows that permittivity is maximum for vitreous humor and minimum for lens.



(a)Sclera

(b) Cornea

(c) Lens

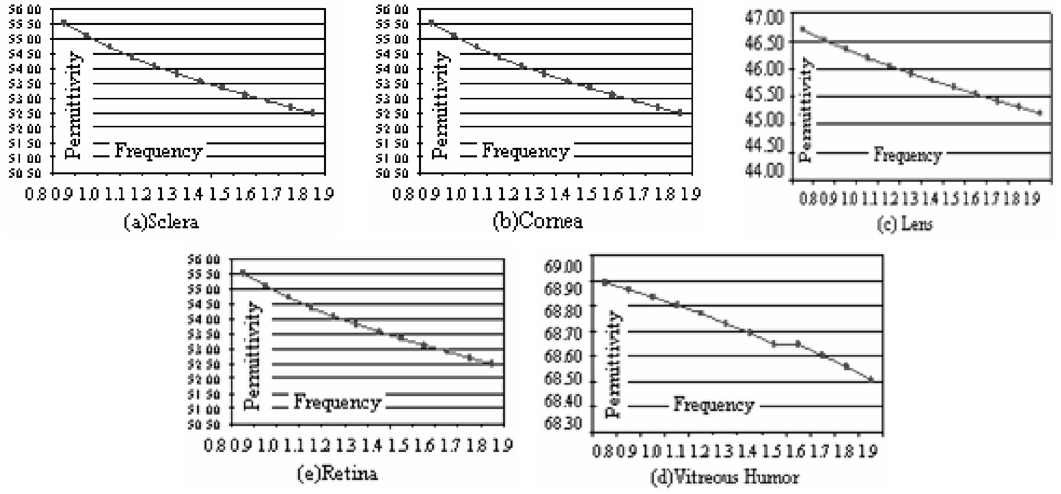


(d)Vitreous Humor

(e)Retina

Figure 1
Mobile phone configuration

Figure 2: Graph representing Conductivity as a function of frequency[7]



(a)Sclera

(b)Cornea

(c) Lens

(e)Retina

(d)Vitreous Humor

Figure 3 Graph representing Permittivity as a function of frequency [7]

Analysis and Design

Designing specification

Circular waveguide has less attenuation in its dominant mode (TE_{11}) whose cutoff frequency is expressed in (2) [6].

$$fc = \frac{cXnp}{2\pi a} \tag{2}$$

Where, ‘c’ is speed of light, ‘a’ is radius of circular waveguide, Xnp is 1.841 for TE_{11} mode of this waveguide.

SAR Calculation

However, to obtain the SAR distribution needed for this model, SAR is calculated using (3) for time harmonic EM fields [5].

$$SAR = \frac{\sigma}{2\rho}(\hat{E}_x^2 + \hat{E}_y^2 + \hat{E}_z^2) = \frac{\sigma|E|^2}{2\rho} \tag{3}$$

Simultaneously, the heating rate can be related with SAR as expressed in (4)

$$\frac{dT}{dt} = \frac{SAR}{c} \tag{4}$$

Where $\hat{E}_x$, $\hat{E}_y$, and $\hat{E}_z$ are the peak values of the electric field vector components, σ is conductivity (S/m) and ρ the mass density(kg/m^3), E is the internal electric field (rms) value (V/m), c is the specific heat capacity of tissue in $J/(kg°C)$. Assumption is made for the ideal non-thermodynamic circumstances having no heat loss by thermal diffusion, heat radiation or thermo-regulation (blood flow, sweating etc.) [6].

Temperature Calculation

Calculation of the temperature increase inside the EM exposed tissues is done with help of the bio-heat equation (5) [5].

$$C\rho\frac{dT}{dt} = \nabla\left(K\nabla T\right) + \rho SAR + A - B(T - T_b) \tag{5}$$

$$B = C_b W_b = C_b \rho_b \rho F \tag{6}$$

Where T and T_b denote the temperature of tissue and blood (^{0}C) respectively, C is the specific heat of the tissue[J/(kg.°C)], K is the thermal conductivity of the tissue $J/(s.m.°C)$, A the basal metabolic rate (W/m^3), and B is associated to the blood perfusion $[W/(°C.m^3)]$ expressed in (5), C_b = 3900 J/(kg.°C) is the specific heat of blood , W_b is the blood perfusion [$kg/(m^3 s)$], ρ_b =1060 kg/m^3 is the mass density of blood, and F is the blood flow rate for mass unit $m^3/(kg.s)$. It is valid when the temperature increase in tissue is sufficiently small where the thermoregulatory mechanism is negligible. Moreover for microwave exposure, the thermal elevation reaches the steady state after about 2 hrs and so, this is the time of exposure adopted in this paper. This bioheat equation needs the thermal properties of the human eye-substances which are enlisted in table III.The initial temperature distribution is the temperature inside the human tissues without any RF field exposure and its solution is obtained using the steady-state equation (7) derived from (4). The energy concentration in the eyeball is due to the low water content in the tissues surrounding the eye (fat and bone) and to the limited field penetration on human tissues considered frequencies.

$$\nabla\left(K\nabla T\right) + A - B(T - T_b) = 0 \tag{7}$$

Table III : Thermal properties of human eye substances are ρ: mass density (kg/m^3), C:the specific heat of the tissue $[J/(kg°C)]$, K: the thermal conductivity of the tissue $[W/(m°C)]$, B: the term associate with blood flow $[W/(°Cm^3)]$, A: the basal metabolic rate $[W/m^3]$ [3]

Tissues	ρ $[kg/m^3]$	C $[J/(kg°C)]$	K $[W/(m°C)]$	B $[W/(°Cm^3)]$	A $[W/m^3]$
Sclera	1170	4200	0.58	0	0
Retina	1050	3900	0.51	40000	10500
Vitreous humor	1010	4178	0.58	0	0
Lens	1100	3000	0.40	0	0
Cornea	1076	4200	0.58	0	0

Results and Discussions

The SAR and increased temperature values are investigated and simulated results are enlisted in table IV for distance 1.5 cm and 3.5 cm. As distance between RF source and human eye is increased the SAR and temperature are also going to increased. For dielectric resonator the value of Q-Factor should be greater than unity. Table VI depicts that Q- factor is function of frequency and is increased with frequency. The simulated results of SAR at 900 MHz are compared with the reference results [3] at 1.9 GHz and found to be approximately matched as depicted in the table V.

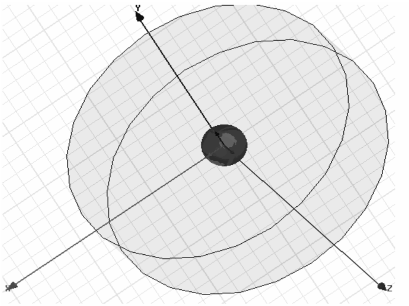


Figure 4 : A Human eye shaped dielectric resonator placed in the center of a circular cylindrical waveguide for its

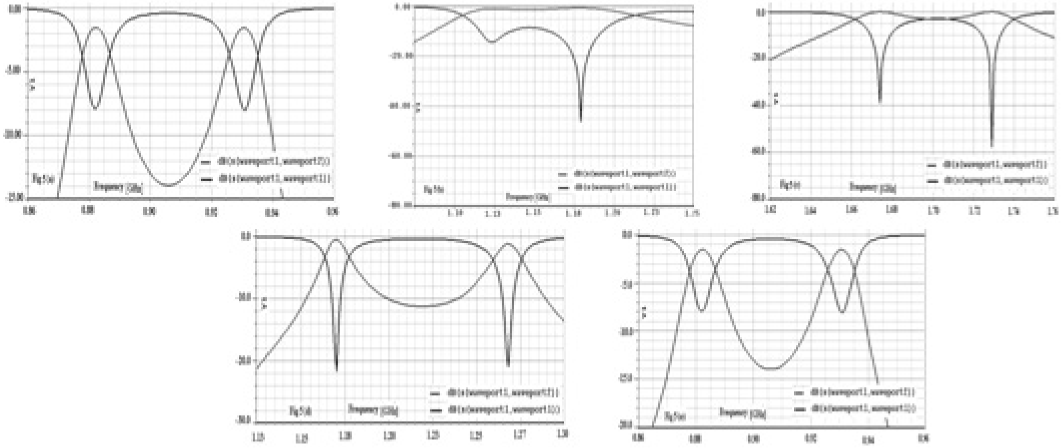


Figure.5 Results for the return loss and insertion loss in tissues (a) Sclera (b) Cornea (c) Lens (d) Vitreous Humor (e) Retina

Table IV : Q-factors of eye substances at (a)935MHz (b)1900MHz

Tissue	d (Cm)	SAR (W/kg)	$\frac{dT}{dt}10^{-3}$ K°/s
Sclera	1.5	7.053	1.6710
	3.5	3.0	0.4814
Retina	1.5	5.718	1.466
	3.5	0.511	0.2569
Vitreous Homor	1.5	13.660	3.269
	3.5	1.002	1.2359
Lens	1.5	11.409	3.8
	3.5	2.022	0.1703
Cornea	1.5	4.1502	0.988
	3.5	5.1636	0.714

Table V : Eye averaged SARs (in W/Kg)

d(cm)	At 900 MHz	d(cm)	At 1.9 GHz
1.5	8.39	1.5	7.76
3.5	3.34	1.5	2.33

Table VI : Induced SAR and maximum temperature of eye substances

Tissue	**Q- Factor**	
	(a) **935 MHz**	**(b)** **1900 MHz**
Sclera	2.43	3.41
Retina	2.432	3.412
Vitreous Homor	2.17	3.488
Lens	3.01	4.01
Cornea	2.033	2.97

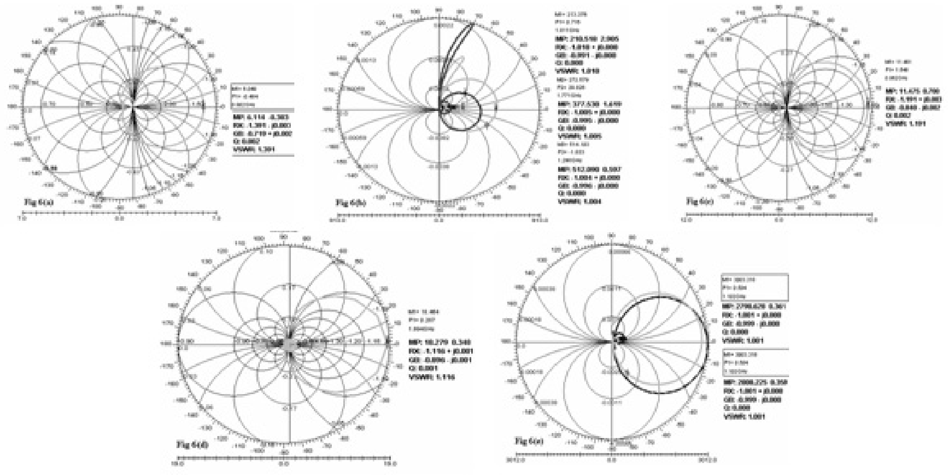


Figure 6 : Smith chart of tissues (a)Sclera(b)Cornea(c)Lens(d)Vitreous Humor (e) Retina

Table VII : Summary of simulated results

Tissue Name	Sub-bands	Central frequency(GHz)	Bandwidth (MHz)	Insertion loss (dB)	Return loss (dB)	Figure no.
Lens	1	~ 1.67	23	0	40	5(c)
	2	~ 1.73	17	0	58	5(c)
Vitreous Humor	1	~ 1.71	11	0.43	21.38	5(d)
	2	~ 1.27	15	1.14	21.38	5(d)
Cornea	1	~1.16	86	1.34	46	5(b)
Retina	1	~0.885	11	1.57	7.57	5(e)
	2	~0.935	10	3.63	8.10	5(e)
Sclera	1	~0.885	11	1.57	7.57	5(a)
	2	~0.935	10	3.63	8.10	5(a)

Conclusion and future perspectives

The dielectric resonator is parametrically investigated for its electromagnetic response for the desired frequencies namely 900 MHz and 1.9 GHz. A comparative study and electromagnetic modeling through time domain numerical analysis is carried out for these frequencies under certain specific assumptions. The resonance behaviors of the human eye substances are found to be similar to the equivalent dielectric resonator for some frequencies. The SAR and increased temperature values are calculated which very closely match with the reference papers published. The future aspirant will find this work to be very useful for carrying out the field experiments and test measurements.

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