The Effect on a Human Heart Model from Dipole Antenna, with and without Shield on SAR and Temperature Increase

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Abstract **─** In this paper, investigate effect of dipole antenna over human heart and a comparative study of temperature increased at heart and specific absorption rate (SAR) without and with different material shields. These structures are modeled and numerically tested by using finite element method (FEM) by using Comsol Multiphysics. The created virtual models using 3D simulation and computation software proved that used shield around human heart reduce the effects of EM fields. The simulation outputs used as measures for this comparative study include the increased temperature and specific absorption rate (SAR), which SAR determines the amount of radiation that human tissue absorb. In addition, study effects of variation of distance of shield from antenna and simulated temperature and SAR.

Index Terms **─** Comsol Multiphysics, dipole antenna, FEM method, SAR.

I. INTRODUCTION

The increasing use of wireless devices has also increased the amount of radiation energy to which human bodies are exposed, so it is important to achieve conditions under which human heart absorbs minimum radiation. For the analysis and assessment of microwaves penetration in human heart, in particular conditions specific to the use of mobile communication devices.

Several anatomical body and tissue models are presented by the scientific literature, like Gabriel and et al. (1996) obtained biologically electric properties (conductivity and permittivity) for 40 types of tissues at different frequencies [1-3].

The most typical example is the use of a mobile phone near human head, and like this, as an example of Baumann's and et al. work in USA (1997) can be mentioned. Baumann worked on electrical conductivity of human cerebrospinal fluid at body temperature. He measured average conductivity and standard deviation of seven cerebrospinal fluid samples at room temperature (25°C) and at body temperature (37°C), across the frequency range of 10 Hz–10 kHz [4]. Schmid and et al. (2000) research examined dielectric properties of the human brain measured less than 10 hours post mortem in the frequency range from 800 to 2450 MHz and for each brain a mean value was calculated from 8 single measurement positions on 20 human brains less than 10 hours after death. The tissue temperature was different for each brain and ranged between 18°C and 25°C [5].

Yioultsis and et al. (2002) performed a comparative study of the biological effects on various mobile phone and wireless LAN antennas simulated by finite difference time domain (FDTD) method. This was one of the first studies that deal with a wide-range comparative investigation of modern cell phones on modern cell phones using monopole, helical, side-mounted planar inverted-F antenna (PIFA), patch antennas and WLAN antenna [6]. Also Ismail and Jenu (2007) modeled of electromagnetic wave penetration in a human head due to emissions from cellular phone by FDTD method by 2D human head model. The results indicated distribution of SAR at different position and at different angle of the phone [7].

Using FDTD method, Faruque and et al. (2010) compared study of a monopole, a helical, a patch and a PIFA antenna at 1.8-2.2 GHz frequency and SAR analyzed in human head tissues [8]. Ragha and Bhatia (2010) evaluated of SAR reduction for mobile phones using RF shields. For reduced SAR in the human head they used RF shield made of a ferrimagnetic material to the front side of the mobile phone. They studied numerically by using field simulation software, CST MWS and FDTD method [9].

Tomovski and et al. (2011) utilized 2D finite difference time domain (FDTD) to obtain the effects of

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electromagnetic field over a human body, SAR simulation with and without nanotextile in the frequency range 0.9-1.8 GHz. The results of this study have been shown that reduction of the SAR levels in the brain tissue is best noticed in the case of usage of both materials (nanoferrite textile and carbon fiber textile shielding). The combined use of textiles with the right properties provided great possibilities for reduction of the RF effects over the human body [10].

Lak and Oraizi (2012) carried out on a numerical simulation the effects the distance of human head model to EM sources has on SAR. Their results have been shown that the distance from exposure source was important. The longer the distance to exposure source is, the lower the amount of SAR will be; therefore, it may be advisable to wear hands free device while using mobile phones, because it keeps phone further away from the head [11]. Islam and et al. (2012) have been studied variability of SAR value of a human head due to different materials in the vicinity of the handset exposed radio frequency electromagnetic fields. They investigated the effects of the human hand, handset chassis and additional conductive material, particularly hand-ring jewelry. FDTD method was used to analyze different positions of the conductive ring materials within the hand model. The results showed holding the mobile phone in a hand reduced the average peak SAR in the head and thus reduced the power absorbed by the head. A ring worn on the human hand caused the SAR distribution to increase because position of the ring behind mobile antenna [12].

But in this case, we find the need to characterize and quantify energy levels absorbed by human heart near dipole antenna with and without shield at 900 MHz and 1800 MHz frequencies (commonly created in real life by mobile GSM system) and using FEM method to carry out numerical calculations.

The parameter used is the specific absorption rate (SAR) representing the levels at which it is absorbed by a mass unit of tissue. Units for expressing SAR are Watt by kilogram of tissue exposed [W/kg]. SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue). In the case of our research, only partial SAR levels are calculated. SAR can be calculated as:

$$SAR = \frac{\sigma |E|^2}{\rho}, \quad (1)$$

where:

σ = conductivity of the tissue (S/m);

ρ = mass density of the tissue (kg/m^3);

E = RMS electric field strength (V/m).

While a-thermal biologic effects are suspected to occur too inside bodies exposed to microwave radiation, the electric field strength and the absorbed power are quantitatively related with the temperature rise and remain the relevant dosimetric indexes currently applied in biophysical research [13].

In this study, a realistic human heart model was used to simulate the SAR distribution and temperature distribution over the realistic human heart at different frequencies and dipole antenna with and without different material shields. Also, location of shield was changed to identify effects of distance between the source and shield.

Electromagnetic waves propagating into human heart were calculated using Maxwell's equations. Heat transfer in human heart exposed to electromagnetic waves was calculated using the bioheat equation [14,15]. The effects of operating frequencies (900 MHz and 1800 MHz) and once without shield and once with shield between the mobile phone and the human heart distributions on SAR and temperature distributions within the human heart were investigated systematically.

II. METHODOLOGY AND MATERIALS

Dipole antenna and its interaction with the heart tissues with and without shield at frequencies 900 and 1800 MHz and change distance of shield are solved by Comsol Multiphysics software and the finite elements method (FEM) is used to carry out most of numerical calculations.

A. Physical model

In this study, it was assumed that antenna of the mobile phone located at the front of human heart, where shield placed between antenna and heart and used different material for shield, and compared between their materials. Information about dielectric properties of tissues is taken from Gabriel [1]. It consisted of electrical properties of some tissues inside a human heart at 900 MHz and 1800 MHz. The dielectric properties of tissues are shown in Table 1.

Table 1: The properties of the tissues

Material	900 MHz			1800 MHz			ρ (kg/m^3)
	ε_r	μ_r	σ (s/m)	ε_r	μ_r	σ (s/m)	
Heart	59.8	1	1.229	56.32	1	1.771	1060
Bone	5.50	1	0.040	5.37	1	0.068	1850
Blood	61.3	1	1.537	59.37	1	2.043	1035
Skin	41.4	1	0.866	38.87	1	1.184	1050
Air	1	1	3e-15	1	1	3e-15	1.16

About this model, we consider shield with height = 8.25 cm, width = 0.45 cm, thickness = 0.3 cm and placed between heart and antenna to evaluate SAR reduction and dimension of antenna is = 8.25 cm (each length = 4 cm and gap = 0.25 cm), width = 0.15 cm, thickness = 0.15 cm. Data were calculated where shield varied from antenna distance of 2, 4, 6, 8 and 10 mm. For shield we selected aluminum from conductor material and mica and teflon from insulator material, with parameters in Table 2 to investigate effect of material which used in shield.

Table 2: Dielectric parameters of shield material

Shield Material	900 MHz			ρ (kg/m³)
	ε_r	μ_r	σ (s/m)	
Aluminum	1	1.000021	3.96e7	2700
Mica	1	6	1e-15	2883
Teflon	1	2.1	1e-20	2200

B. FEM implementation and boundary condition

FEM methodology was derived from Maxwell equations which mathematically describe the interdependence of the electromagnetic waves. Maxwell's equations were simplified to demonstrate the electromagnetic field penetrated in human heart as follows:

$$\nabla \times \frac{\nabla \times E}{\mu_r} - k_0^2 \varepsilon_r E = 0, \tag{2}$$

where E is the electric field intensities (V/m), μ_r is relative magnetic permeability, ε_r is relative dielectric constant and k_0 is the free space wave number (m^{-1}).

Electromagnetic energy is emitted by the dipole antenna and strikes the human heart with a particular radiated power. The lumped port was used to determine a voltage drop for center feed legs of antenna. And on the antenna, an electromagnetic simulator employs lumped port boundary conditions with specified radiated power:

$$Z_{in} = \frac{V}{I} = \frac{EL}{I}, \tag{3}$$

where Z_{in} is the input impedance (Ω), V is the voltage along the edges (V), I is the electric current magnitude (A), E is the electric field along the source edge (V/m) and L is the edge length (m). The dipole must be made in odd number of half wavelengths long, with the basic dipole being only 1/2 wave of a wavelength long.

For all cases, the dipole antenna shown in Fig. 1 was modeled as a perfect electric conductor (PEC) box having length (L) = 4 cm, considering feeding with input power of 1 Watt, impedance is Z = 50 Ω, and distance from heart is 1 cm. The patch of the antenna acts approximately as a cavity which assuming the perfect electric conductor on inner and outer surfaces is assumed. Hence, the perfect-electric-conductor boundary condition along the patches on the antenna is considered:

$$n \times E = 0. \tag{4}$$

Boundary conditions along the interfaces between different mediums, for example, between air and tissue or tissue and tissue or tissue and shield, were considered as continuity boundary condition:

$$n \times (E_1 - E_2) = 0. \tag{5}$$

Outer sides of the calculated domain, i.e., free space, were considered:

$$n \times (\nabla \times E) - jkn \times (E \times n) = -n \times (E_0 \times jk(n-k)\exp(-jk.r)). \tag{6}$$

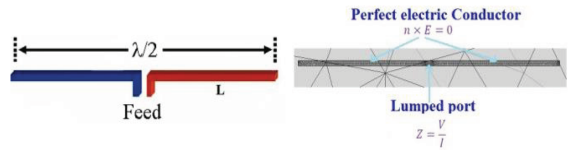


Fig. 1. Dipole antenna.

Therefore, boundary conditions for solving electromagnetic wave propagation, as shown in Fig.2, are described as follows.

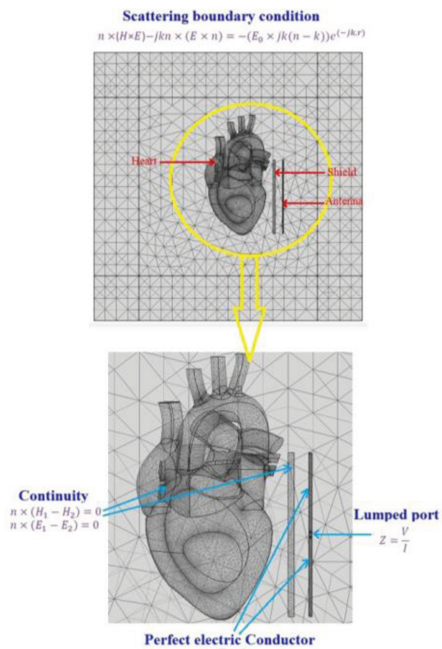


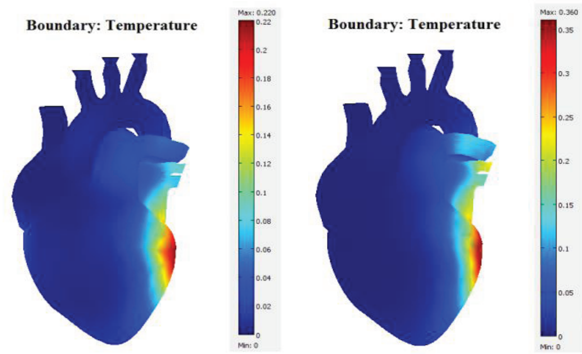
Fig. 2. Boundary conditions and mesh.

III. RESULTS AND DISCUSSION

Effects on a human heart model from dipole antenna at 900 MHz and 1800 MHz frequencies, with and without shield on SAR were studied, computed and simulated. Figure 3 (a) shows local temperature increases (from 37°C) without shield at frequency 900 MHz and Fig. 3 (b) shows it at frequency 1800 MHz.

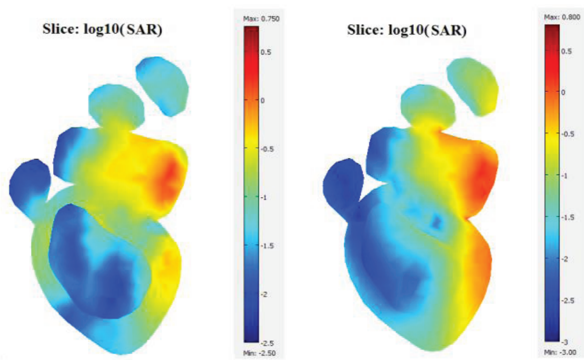
Figure 3 shows that increase in heart temperature is more at frequency 1800 MHz than at 900 MHz one, also at 1800 MHz the former covers more with of heart. Maximum temperature increases, as seen from figure, are about 0.36°C and 0.22°C at 1800 MHz and 900 MHz frequencies, respectively, at the closest point of heart to antennas where the distance is 1 cm.

The differences in electrical properties become visible by plotting the local SAR value on a log-scale; so Fig. 4 (a) shows the results for log-scale slice plot at frequency 900 MHz obtained due to radiation sources without shield and distance between antenna and heart is 1 cm, and Fig. 4 (b) shows at frequency 1800 MHz.



(a) Frequency = 900 MHz (b) Frequency = 1800 MHz

Fig. 3. Increase in temperature heart at: (a) 900 MHz and (b) 1800 MHz without shield.



(a) Frequency = 900 MHz (b) Frequency = 1800 MHz

Fig. 4. Log-scale slice plot of the SAR value heart at: (a) 900 MHz and (b) 1800 MHz without shield.

Results show that the increase in frequency cause increase in SAR value and temperature. But near antenna more increased temperature difference than far from antenna and difference between SAR values like temperatures. So far from antenna difference temperature and SAR value at both frequencies are same but near antenna have different values.

As Fig. 5 shows, the heart line close to the center of antennas was selected to analyze temperature and SAR values in all models. Figure 6 illustrated comparison temperatures and Fig. 7 illustrated SAR values. As expected, heart temperature and SAR value exhibited some increases at points close to antennas, as shown in Figs. 6 and 7.

It is interesting to note that, for dipole antenna, depths of temperature penetration into human heart were similar for both 900 MHz and 1800 MHz frequencies as shown in Fig. 6, but the maximum temperature increase in skin and heart at 1800 MHz frequency is higher than that at 900 MHz frequency. The SAR value in skin of 1800 MHz frequency is higher than that of 900 MHz frequency but in heart of 1800 MHz is lower than that of 900 MHz frequency.

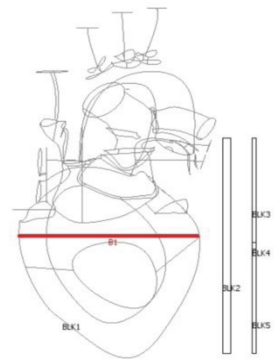


Fig. 5. Line of points selected for comparison purposes.

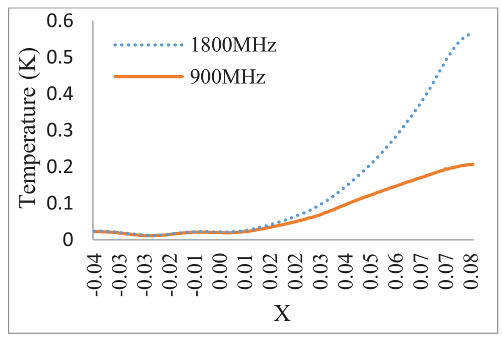


Fig. 6. Comparison of results for heart temperatures increases at 900 MHz and 1800 MHz without shield.

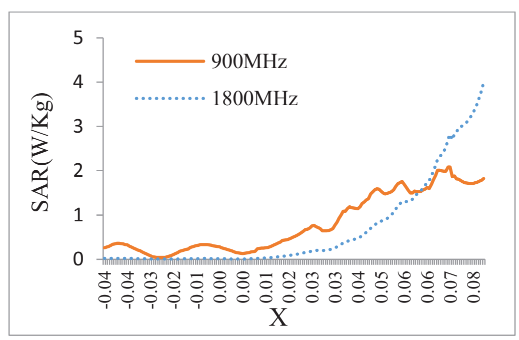
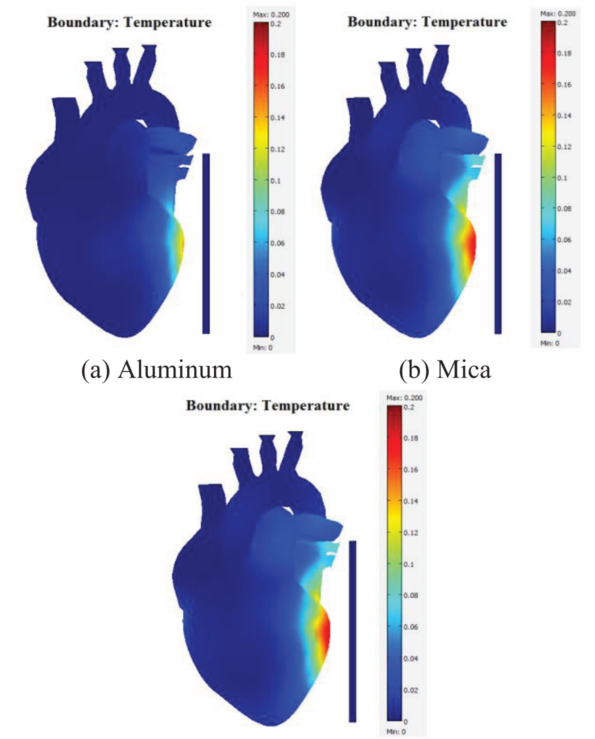


Fig. 7. Comparison of results for SAR values at 900 MHz and 1800 MHz without shield.

Figure 8 illustrated the temperature distribution in human heart exposed to mobile phone radiation with different material used for shield. For human heart exposed to the mobile phone radiation with a different material shield, the temperature within the human heart has different temperature increased, it is found comparison of them at Fig. 9.



(a) Aluminum (b) Mica

(c) Teflon

Fig. 8. Increase in temperature heart at 900 MHz with different material shields.

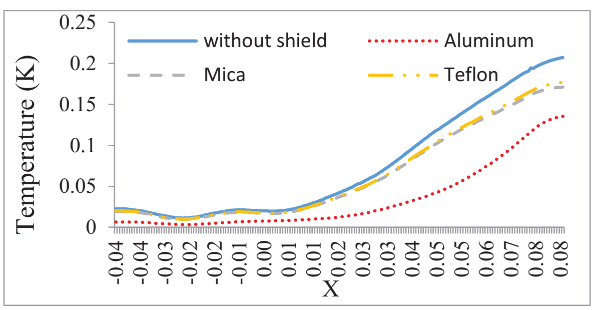
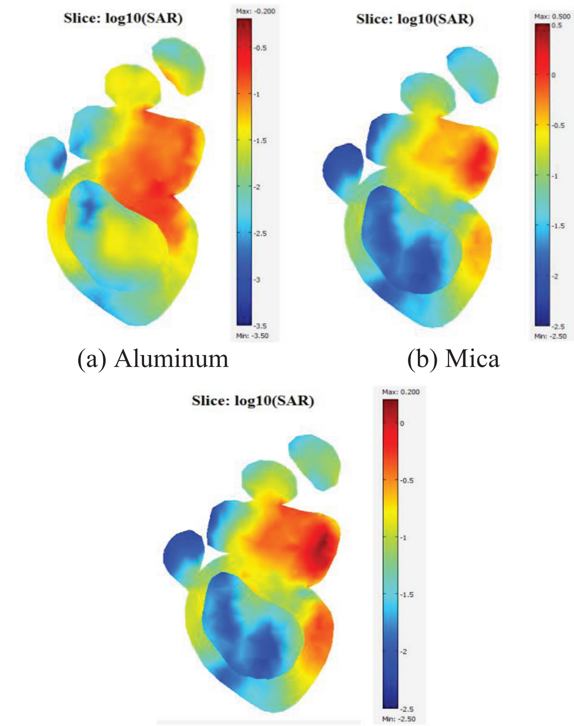


Fig. 9. Comparison of results for heart temperature increase at 900 MHz with different material shields.

More carefully study of above figures indicates that the aluminum is better material to reduce effect of electromagnetic field because the conductivity value of that is more than other and the region with high absorption values is small and close to the feed point of the antenna.

Figure 10 illustrates the penetration of the local SAR value on a log-scale in a 3D human heart due to different material shield. It is found comparison of them at Fig. 11. The results show that change material of shield, depth of temperature and SAR value are different as shown in Figs. 8 to 11 penetrates into a human heart with aluminum is lower than others, but in view of the fact that the temperature distribution always correlate with the SAR value. More carefully study of above figures indicates that the aluminum is better material for reduce effect of electromagnetic field.



(a) Aluminum (b) Mica

(c) Teflon

Fig. 10. Log-scale slice plot of the SAR values heart at 900 MHz with different material shields.

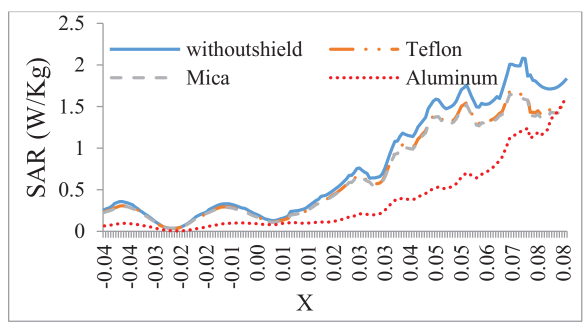


Fig. 11. Comparison of results for SAR values heart at 900 MHz with different material shield.

Obviously SAR and temperature are decreased by increasing the distance from exposure source [11]. So at Fig. 12 illustrates temperature increases (from 37 C) where distance between shield (select aluminum for material of shield) and antenna is varied 2, 4, 6, 8, and 10 mm, respectively. In constant distance between heart and antenna, by increasing the distance of shield from antenna temperature and SAR values increase and the results show that the distance from exposure source is important and if shield is near antenna the temperature of heart is decreased.

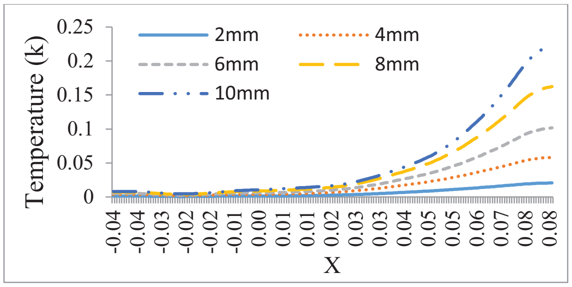


Fig. 12. Comparison of results for heart at 900 MHz where change position of shield.

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