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SAR Simulation in Human Head Exposed to RF Signals and Safety Precautions

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Abstract*— As the number of mobile phone users is increasing rapidly, it has become main concern to focus on the effect of radio frequency electromagnetic radiations produced by mobile phone. At communication frequency, human body behaves as a dielectric and the EM radiation generated by mobile phone are able to penetrate through semisolid substances like living tissues and meat etc. The EM radiation is called the fourth pollution source besides air, water and noise by the environmentalists. And that how to protect against it and calculate it grows to a primary problem. In this paper, the maximum Specific absorption rate (SAR) averaged over 1g and 10g of tissue inside homogenous human head model has been investigated for dual-band PIFA antenna operating in the 900 MHz and 1800 MHz frequency bands. The human head model consists of a uniform core representing human brain, surrounded by shell representing head skull and skin. All Simulations are performed using CST-Microwave studio. The provided antenna is re-optimized in the presence of head and hand because the provided antenna has a very bad performance. SAR is obtained at various distances between the head and mobile and at various input powers with and without the proposed shield. It is shown that SAR decreases as the distance between the head and the mobile phone increases. The calculated maximum average SAR values in the head are compared with SAR limits in the safety standards of the International organizations. The maximum local SAR becomes more than the FCC and ICNIRP's upper safety limits for high input powers. SAR reduction issue is considered in this paper also. Reducing SAR in the head model is effectively achieved by attaching the suggested shield on a mobile phone. The designed shield is made from ferrite and aluminum material. The results revealed that the use of the proposed shield will reduce effectively the SAR value averaged over 1g and 10g of tissues by 53.68% and 63.8% respectively for 900MHZ band and will reduce the SAR averaged over 1g and 10g of tissues by 63.72% and 61.03% for 1800MHZ.

***Keywords*— SAR, SRF, Mobile phone, RF shield, SAR Distribution.**

I. INTRODUCTION

By the widespread wireless device applications, such as mobile phones, the persons, and operators living and working in near electromagnetic sources, the biological effects of exposure to these electromagnetic fields are an important subject. The safety standards, such as the Federal Communication Commission (FCC) and the International Commissions on Nonionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE), are established for human protection and safety from electromagnetic fields [1].

When electromagnetic waves propagate through the human tissues, the energy of electromagnetic waves is absorbed by the tissues [2]. So SAR is defined as the amount of power dissipated per unit mass, and its unit is watt per kilogram (W/kg) [3].

$$SAR = \frac{\sigma \cdot E^2}{\rho} \qquad \text{... (1)}$$

Where σ (S/m) is the conductivity of the biological material, ρ (kg/m^3) is the material density, and E (V/m) is the electric field strength [4]. SAR is preferred as low as possible to minimize the biological Effect [5]. The guideline that provides SAR exposure limit of 1.6 W/kg for any 1 g of tissue was approved by the IEEE in 1991 and was subsequently adopted by the American National Standards Institute (ANSI) in 1992 as a replacement for the previous (ANSI C95.1-1982 guideline). In April 1993, the FCC proposed using the ANSI/IEEE C95.1-1992 for evaluating environmental RF fields created by transmitters it licenses and authorizes [6,7]. IEEE C95.1-2005 the newly approved standard represents a complete revision of and replaces IEEE Standard C95.1-1991 [6]. The SAR limit specified in IEEE C95.1: 2005 has been updated to 2 W/kg over any 10-g of tissue. This new SAR limit specified in IEEE C95.1: 2005 is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [8].

One way of reducing SAR in the human head is by attaching RF shield to the front side of the mobile phone. The effectiveness of the RF shield can be specified in terms of an SAR reduction factor (SRF) and is defined as follows:

$$\mathrm{SRF}_{10g}\,(\%) = \frac{SAR_{10g} - SAR_{10g,s}}{SAR_{10g}} \times 100 \qquad \text{... (2)}$$

$$\mathrm{SRF}_{1g}\,(\%) = \frac{SAR_{1g} - SAR_{1g,s}}{SAR_{1g}} \times 100 \qquad \ldots (3)$$

Where $\mathrm{SRF}_{10g,}$ is SRF for 10g peak SAR, SRF_{1g} is SRF for 1g peak SAR, SAR_{10g} is 10g peak SAR (without RF shielding), $\mathrm{SAR}_{10g,s}$ is 10g peak SAR(with RF shielding), SAR_{1g} is 1g peak SAR (without RF shielding), and $\mathrm{SAR}_{1g,s}$ is 1g peak SAR (with RF shielding). Larger SRF value implies greater shielding effectiveness [9].

II. MODELING

CST MWS version 2010 is used for modeling and SAR analysis. This model contains three parts: head, hand and mobile phone as shown in Fig. 1.

Fig. 1 Mobile phone, SAM head and hand

Standard Anthropomorphic Model (SAM) head is a homogeneous model of the human head composed of two parts: fluid and shell as shown in Fig. 2. SAM was created for measurements Filled with head tissue equivalent materials, only two head tissue equivalent materials is needed to simulate fluid and shell [10].

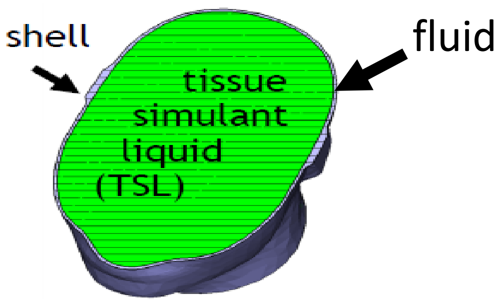


Fig. 2 Component of homogeneous head model **[10]**

The dielectric properties of SAM head model that used in simulations which equivalent to human head tissues are given in Table 1. The thickness of the shell is 1.5 cm. Because of the density of various tissues in the human body is closer to the density of water, ρ =1000kg/m^3 was taken in calculations [11]. The properties of the homogenous hand that used in simulation are given also in Table 1.

TABLE 1 DIELECTRIC PROPERTIES OF THE HUMAN HEAD AND HAND TISSUES **[12, 13, 14, 15, 16]**

	Tissue Type & Frequency	ε_r	σ
SAM phantom head	shell	3.7	0.0016
	Liquid @ 900 MHZ	41.5	0.97
	Liquid @ 1800 MHZ	40	1.4
hand	@ 900 MHZ	36.2	0.79
	@ 1800 MHZ	32.6	1.26

The mobile phone that provided by CST Microwave Studio is composed of antenna, circuit, LCD, keyboard and housing; their properties are given in Table 2. A dual-band Planar Inverted-F Antenna (PIFA) operates at 900 MHZ and 1800 MHZ is used as the radiating antenna, which is shown in Fig. 3.

TABLE 2 THE ELECTRICAL PROPERTIES OF THE HANDSET MATERIALS THAT USED FOR SIMULATION **[12, 17, and 18]**

Phone Materials	ε_r	σ	**loss tangent**
Circuit board	4.4	_	0.02
Housing plastic	2.5	0.005	_
Lcd display	3.0	0.02	_
rubber	2.5	0.005	_

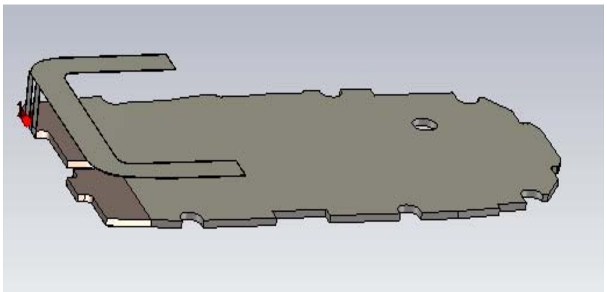


Fig. 3 The provided dual-band Planar Inverted-F Antenna

Return loss and radiation pattern of the provided antenna in the presence of the SAM head and hand are shown in Fig. 4.

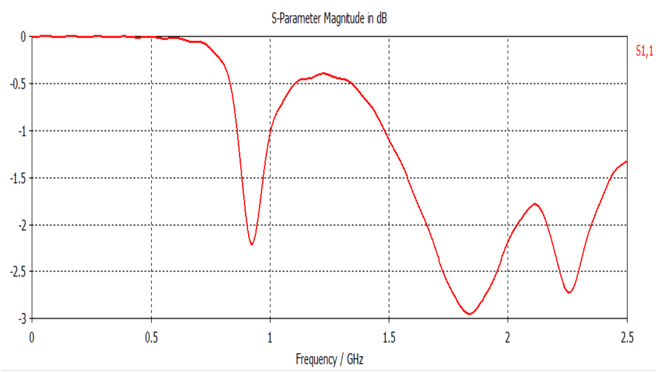


Fig. 4 Return loss of the antenna in the presence of the SAM head and hand

The performance of dual-band PIFA antenna used in the simulation was affected by the presence of the hand and head, as shown in Fig. 4, therefore; to overcome this drawback, handset antenna need to be re-optimized in the presence of the human hand and head. In this work, tuning the resonant frequencies of both bands is made by trial and error, and the re-optimized antenna can be seen in Fig. 5.

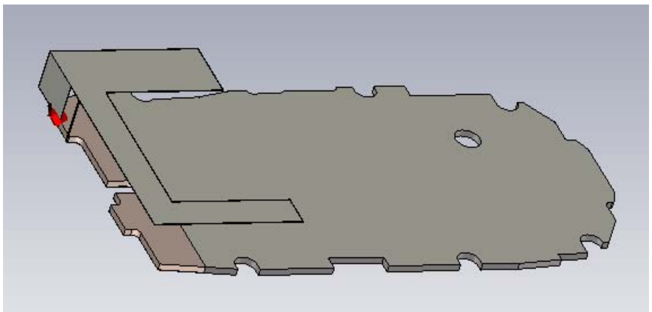


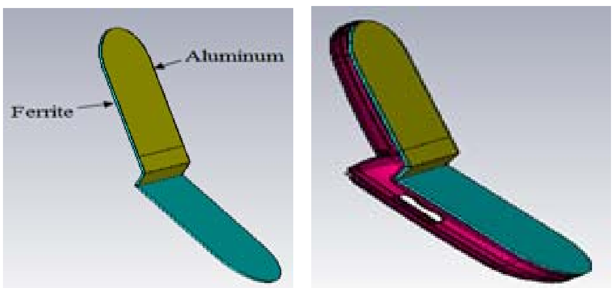
Fig. 5 The re-optimized antenna in the presence of the head and hand

III. Proposed Method For SAR Reduction

Different kind of shield is proposed to reduce the amount of power absorbed in the head which leads to minimize the health effect on the human body. This shield composed of two layers as seen in Fig. 6, one made of ferrite material of 1mm thickness and the other of aluminum of 0.1mm thickness, attached to the front side of the mobile phone. Full layer of ferrite is used because it is better than other types of shield. A half layer made of aluminum is used to get a better reduction. Shield properties that used in simulations are given in Table 3.

Table 3 The electric properties of RF shield materials **[19, 20]**

RF Shield materials	ε_r		μ_r		σ
	Re	***Im***	***Re***	***Im***	
Ferrite	18	15	15	17	_
Aluminum	_		1		3.77×10^{7}



-a- -b-

Fig. 6 a) The proposed shield b) The proposed shield attached to the mobile phone

IV. Results And Analysis

A. Results of PIFA's Antenna Tuning

PIFA antenna is re-optimized by tuning its parameters to get a better performance when the handset and hand in the vicinity of head, the re-optimized antenna's return loss and radiation pattern in the presence of head and hand are shown in Fig. 7 and Fig. 8 respectively.

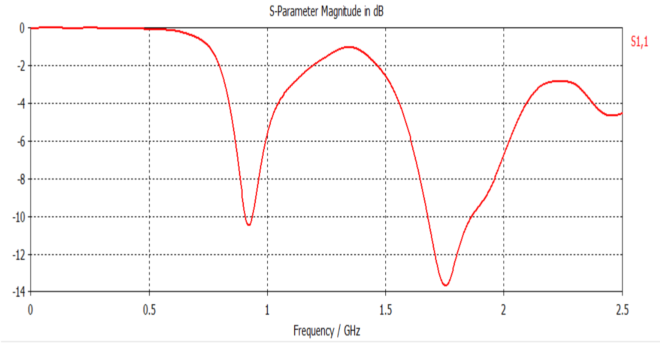


Fig. 7 Simulated return loss of the re-optimized antenna in the presence of head-hand

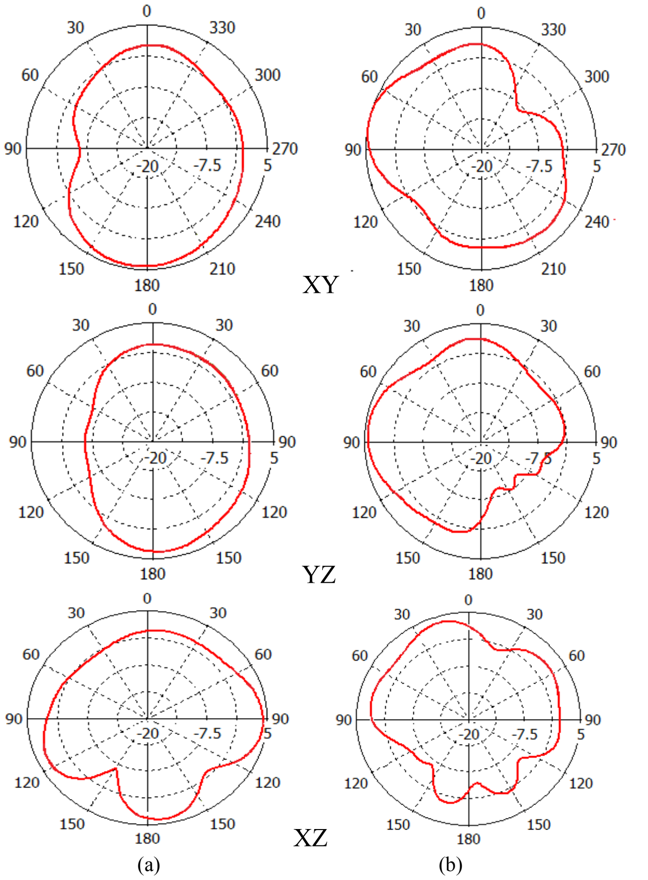


Fig. 8 Simulated radiation patterns of the re-optimized antenna in the presence of head and hand on the XY, YZ and XZ planes at a) 900MHZ and b) 1800MHZ

B. The proposed mobile antenna shield simulation results

For SAR reduction, an external shield is proposed. The shield composed of two layers whose properties are mentioned before in Table 3. The effect of shield on the re-optimized antenna (the re-optimized antenna in the presence of the head and hand) performance and radiation pattern is shown in Fig. 4-9 and Fig. 4-10. There is a slight variation in return loss and radiation pattern with the use of RF shield but still accepted.

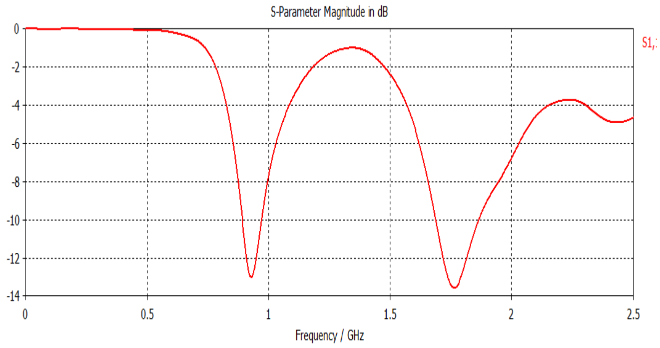
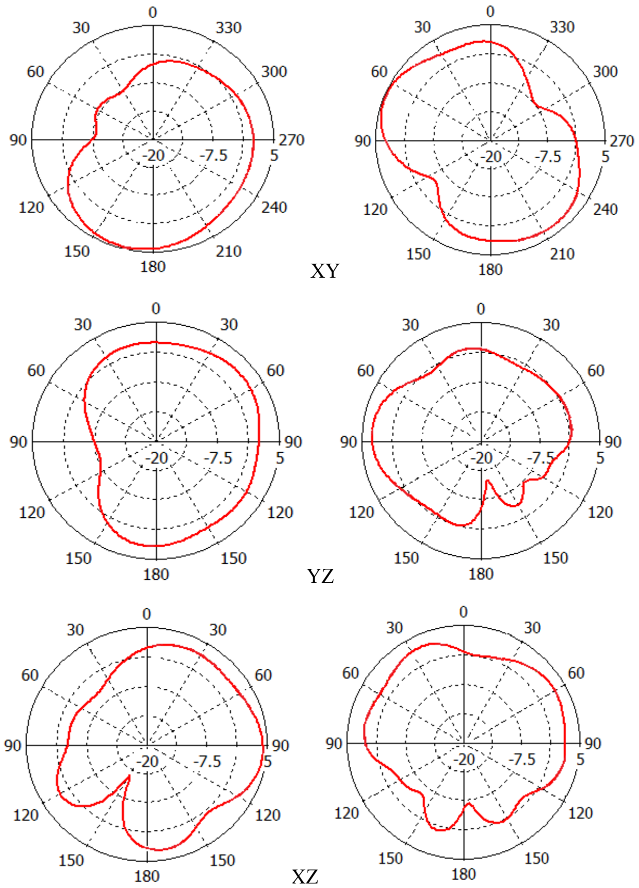


Fig. 9 Simulated return loss of antenna after using the proposed shield



-a- 900 MHZ -b- 1800 MHZ

Fig.10 Simulated radiation patterns of antenna after using the proposed shield on the XY, YZ and XZ planes at a) 900MHZ and b) 1800MHZ

C. SAR simulation Results

Using CST MWS version 2010, SAR is extracted before using the proposed shield and after using it. The re-optimized antenna in the presence of head and hand is used in simulations. The data presented in this section is logged in MATLAB file format using MATLAB Version R2008a.

1) SAR results using modified antenna:

To calculate SAR before shield using, the properties in Tables 1 and 2 are used. SAR is calculated at various distances for various input powers for both bands (900 MHZ and 1800MHZ), and for 1g and 10g averaging. Simulated SAR over 10g results is shown graphically in Fig. 11 and 12.

Fig. 11 and Fig. 12 show how SAR values drop as the distance between the antenna and SAM head increase for both bands (900, 1800) MHZ. Also, the higher SAR value result of the higher input power. Also, all SAR values in 1800 MHZ band are less than SAR values in 900 MHZ band. A further point to note is that SAR value is larger when the handset is close to the head than any other distance.

For 900 MHZ band, for input powers (0.2, 0.3, 0.4, 0.5) watt, SAR values are in line with the standardized limit set by ICNIRP guidelines, while for higher powers (0.6, 0.7, 0.8, 0.9, 1) watt the antenna should be at least at 2mm to 10 mm distance from the head as seen in Fig. 11.

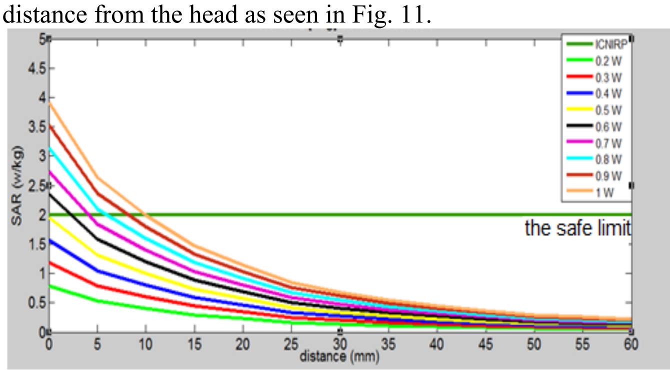


Fig. 11 SAR Vs. Distance for 900 MHZ over 10g

Figure 12 shows that for 1800 MHZ band SAR values for all input powers at any distance are below the standardized limit of the ICNIRP guidelines.

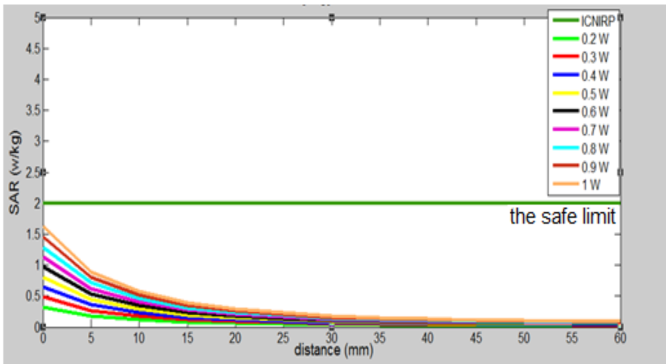


Fig. 12 SAR Vs. Distance for 1800MHZ over 10g

Results of SAR average over 1 g for 900 MHZ and1800 MHZ bands are shown graphically in Fig. 13 and 14. These figures (Fig. 13 and Fig. 14) show the same in common conclusions that figured out before from Fig. 11 and Fig. 12 which are: SAR values drop as the distance between the antenna and the phantom head increase for both bands (900, 1800) MHZ . Also, higher input power result in higher SAR value. Also, all SAR values in 1800 MHZ band are less than SAR values in 900 MHZ band. A further point to note is that SAR values of 10g averaging is always smaller than 1g averaging.

For 900 MHZ band, for reference powers 0.2w SAR values are in line with the standardized limit, set by FCC guidelines, while for (0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1) watt the antenna should be at least at 2 mm to 20 mm from the head as seen in Fig. 13.

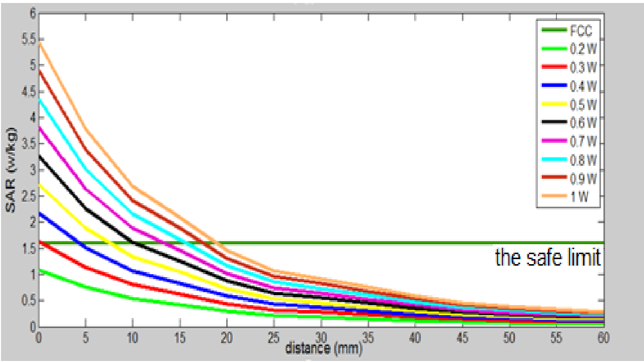


Fig. 13 SAR Vs. Distance for 900MHZ over 1g

For 1800 MHZ band, for input powers (0.2, 0.3, 0.4, 0.5) watt SAR values are in line with the standardized limit, set by FCC guidelines, while for (0.6, 0.7, 0.8, 0.9,1) watt the antenna should be at least at 2 mm to 5 mm spacing from the head as seen in fig 14.

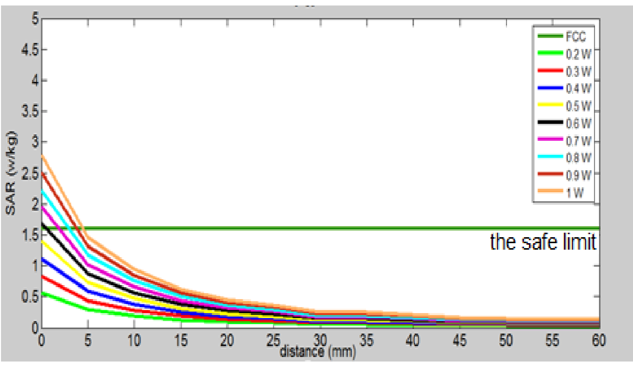


Fig. 14 SAR Vs. Distance for 1800MHZ over 1g

If 0.3w is taken as input power and the handset is set close to head, SAR distribution in head over 1g and 10g of tissue for both bands is shown in Fig. 15, 16, 17 and 18.

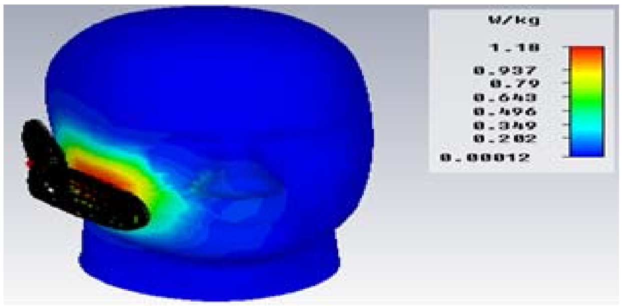


Fig. 15 SAR distribution for 900 MHZ over10g

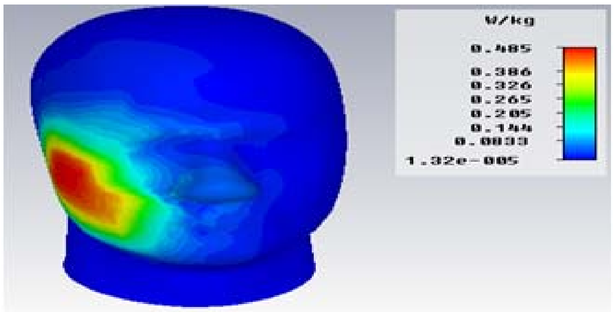


Fig. 16 SAR distribution for 1800 MHZ over 10g

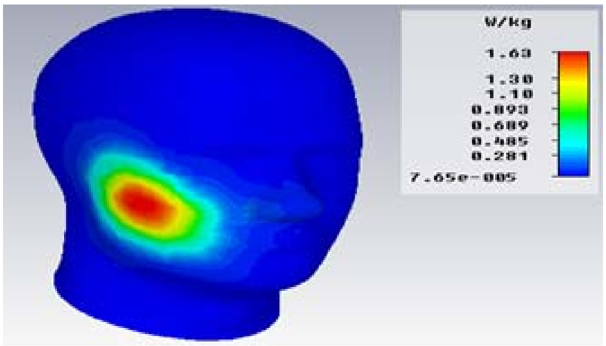


Fig. 17 SAR distribution for 900 MHZ over 1g

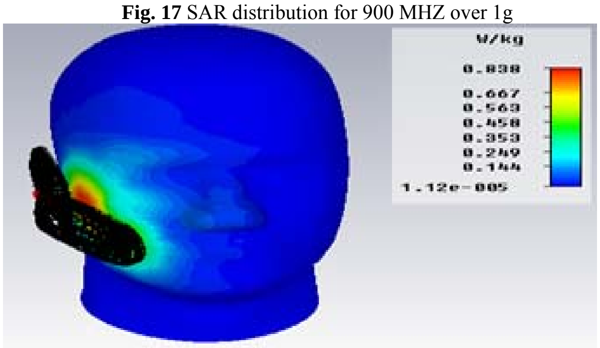


Fig. 18 SAR distribution for 1800 MHZ over 1g

2) SAR results using shield materials:

By using Table 1, 2 and 3, SAR reduction using the proposed shield is simulated. Exactly the same procedure of the first case (calculating SAR before reduction) is done. Simulated averaged SAR results over 10g is shown in Fig. 19 and 20. From the mentioned figures it can be seen that SAR values for all input powers for both bands at any distance are under the limit that set by ICNIRP because of the impact of the proposed shield.

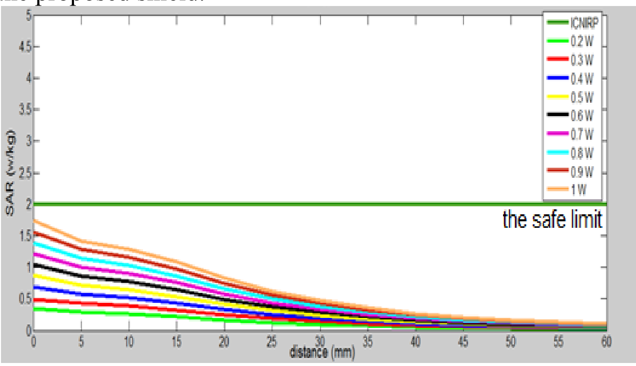


Fig. 19 SAR Vs. Distance for 900MHZ band over 10g, with shield

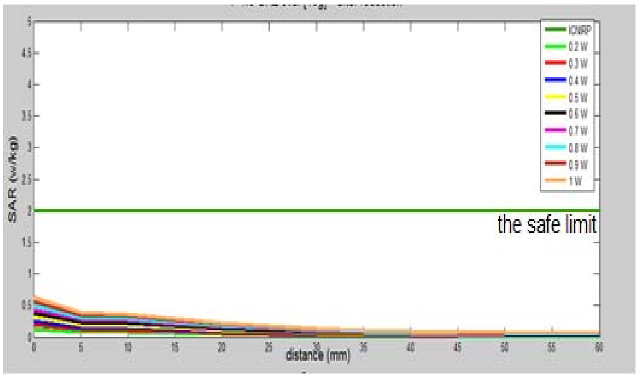


Fig. 20 SAR Vs. Distance for 1800MHZ band over 10g, with shield

As mention before, the effectiveness of the RF shielding can be specified in terms of an SAR reduction factor (SRF), to estimate the effectiveness of the proposed shield for any 10g of tissue, equation (2) is used which is:

$$\mathrm{SRF}_{10\mathrm{g}}\,(\%) = \frac{SAR_{10g} - SAR_{10g,s}}{SAR_{10g}} \times 100 \qquad \text{... (2)}$$

If 0.3 w is taken as input power and the hand set is close to head and the band is 900 MHZ, SRF value will be:

$$\mathrm{SRF}_{10\mathrm{g}}\,(\%) = \frac{1.18 - 0.427}{1.18} \times 100$$

$$\therefore\ \mathrm{SRF}_{10\mathrm{g}}\,(\%) = 63.8\%$$

If 0.3 w is taken as input power and the hand set is close to head but the band is 1800 MHz this time, SRF value will be:

$$\mathrm{SRF}_{10\mathrm{g}}\,(\%) = \frac{0.485 - 0.189}{0.485} \times 100$$

$$\therefore\ \mathrm{SRF}_{10\mathrm{g}}\,(\%) = 61.03\%$$

Results of average SAR over 1 g for 900 MHZ and 1800 MHZ bands are shown in Fig. 21 and 22. For 900 MHZ band, for input powers (0.2, 0.3, 0.4, 0.5, 0.6) watt SAR values are in line with the standardized limit, set by FCC guidelines, while for (0.7, 0.8, 0.9,1) watt the antenna should be at least at 3 mm to 12 mm from the head as seen in Fig. 21.

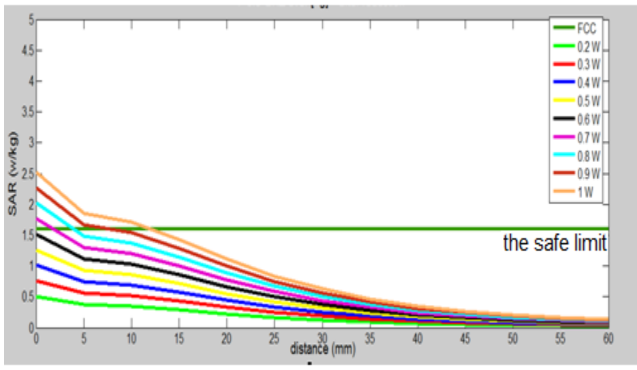


Figure 21 SAR Vs. Distance for 900 MHZ band over 1 g, with shield

From figure 22 it can be seen that SAR values for all input powers at any distance for 1800 MHZ band are under the limit that set by ICNIRP.

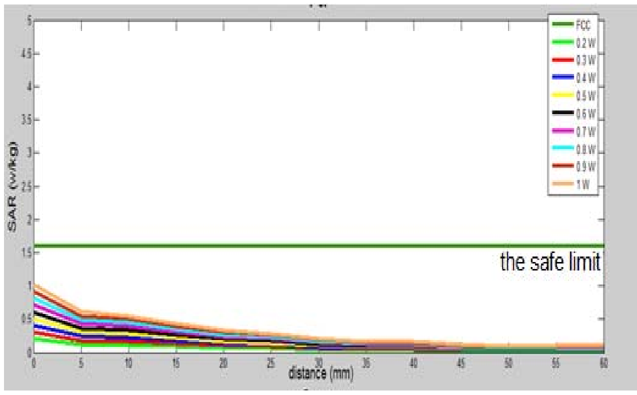


Figure 22 SAR Vs. Distance for 1800MHZ band over 1 g, with shield

To estimate the effectiveness of the proposed shield for any 1g of tissue, equation (3) is used which is:

$$\mathrm{SRF}_{1\mathrm{g}}\,(\%) = \frac{SAR_{1g} - SAR_{1g,s}}{SAR_{1g}} \times 100 \quad \text{... (3)}$$

If 0.3 w is taken as input power and the hand set is close to head and the band is 900 MHz, SRF value will be:

$$\mathrm{SRF}_{1\mathrm{g}}\,(\%) = \frac{1.63 - 0.755}{1.63} \times 100$$

$$\therefore\ \mathrm{SRF}_{1\mathrm{g}}\,(\%) = 53.68\,\%$$

Again, if 0.3 w is taken as an input power and the hand set is close to head but the band is 1800 MHz this time, SRF value will be:

$$\mathrm{SRF}_{1\mathrm{g}}\,(\%) = \frac{0.838 - 0.304}{0.838} \times 100$$

$$\therefore\ \mathrm{SRF}_{1\mathrm{g}}\,(\%) = 63.72\,\%$$

V. CONCLUSIONS

Based on the study and work conducted in this paper, it can be concluded that:

- There is an inversely proportional relation between SAR and the separation distance of the handset antenna from the head. To be safe, the mobile phone should be at least 20 mm away from the head (according to FCC standard) and at least 12 mm (according to ICNIRP standard) for the worst case where the highest input power 1 w is considered.
- Higher SAR values obtained for higher power. For a specific power, higher SAR value estimated when the mobile phone is in the vicinity of head (when the handset is close to the head than at any other distance). For safety, the antenna input power must be less than 0.5 w and 0.3 w according to ICNIRP and FCC standards respectively.
- SAR values in 1800 MHZ band are less than SAR values in 900 MHZ band.
- The shield with proper design can be used to reduce effectively SAR values averaged over 1g and 10g of tissues by 53.68% and 63.8% respectively for 900MHZ band , also, will reduce the SAR averaged over 1g and 10g of tissues by 63.72% and 61.03% respectively for 1800MHZ.
- The obtained resonance frequencies in case of attaching shield using do not vary significantly when compared with the case without the shield, and the radiation pattern of antenna can be less affected.
- The deigned shield is very useful for SAR reduction, but it should compatible with the mobile phone type.

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