SAR Analysis in Human Head Tissues
for Different Types of Antennas

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Abstract: The aim of this paper, a comparative study of several antennas commonly used in portable telephones is investigated. These include a monopole, a helical, a patch and a PIFA antenna. Each one of these structures is modelled and numerically tested using CST Microwave Studio. The testing procedure involves antenna simulation in the proximity of the human head and hand. The behavior of each antenna is evaluated for variable distances from the head geometry (0-20 mm). The simulation outputs used as measures for this comparative study include the specific absorption rate (SAR). The computed SAR levels within each of the considered tissues vary for the four antennas under investigation and are within the determined health safety standards.

Key words: FDTD method · Helical antenna · Monopole antenna · Portable telephones radiation · PIFA antenna · Patch antenna · SAR

INTRODUCTION

Interaction of handset antennas with human body is a great consideration in cellular communications. The user's body, especially head and hand, influence on the antenna voltage standing wave ratio (VSWR), gain and radiation patterns. Furthermore, thermal effect, when tissues exposed to unlimited electromagnetic energy, can be a serious health hazard. So standard organizations have set exposure limits in terms of the specific absorption rate (SAR) [1-2].

Simplified phone antennas such as half-wavelength dipoles in free space or quarter-wavelength monopoles mounted on a metallic box have been frequently investigated in the literature. At the present time PIFA and helical antennas are two commonly used handset antennas. Today, the handset antennas are designed to be able to support two or more frequency bands of various cellular networks. It is required to perform a comprehensive study to determine which handset antenna has better performance and less health hazard. Also it is needed to determine which frequency band is better for operation [3-5].

In one of the first investigations in this area [5], a comparative study has been performed among a monopole antenna and some different types of single band PIFA antennas. Size of the investigated antennas and length of handset boxes used in [5] are considerably greater than those used today. SAR and temperature rise in a human head have been calculated for electromagnetic radiation from a monopole, single band helical and side mounted single band PIFA antenna at 900 MHz and 1800 MHz [6]. Effect of the separation distance between the antenna and user head has been studied for a dual band PIFA handset antenna [8]. This study has shown that there is a proportional relation between SAR and antenna efficiency. In [9], SAR induced in a cubic head model by two single band helical antenna, one radiates at 900 MHz and the other radiates at 1800 MHz, has been calculated and the effect of mobile shell material has been studied. SAR and radiation efficiency has been measured for four types of PIFA designed for the PCS frequency band (1850 MHz-1990 MHz) and it has been shown that handsets with higher-efficiency antennas might not necessarily have higher total radiated power due to the SAR limit [10]. The head loss for twenty different mobile phones, with external and built-in antennas, has been measured [11-12]. The measured results have been compared; it has been shown that the handsets with built-in antennas are much less sensitive to how the phone is held than the handsets

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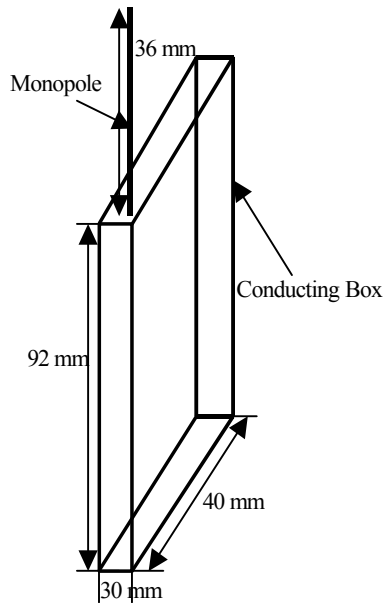
Fig. 1: Monopole antenna. All the dimensions in the sketch are given in millimeters. The monopole is fed with a 250-mW, 1.8-2.2 GHz source and the casing is used to define the ground.
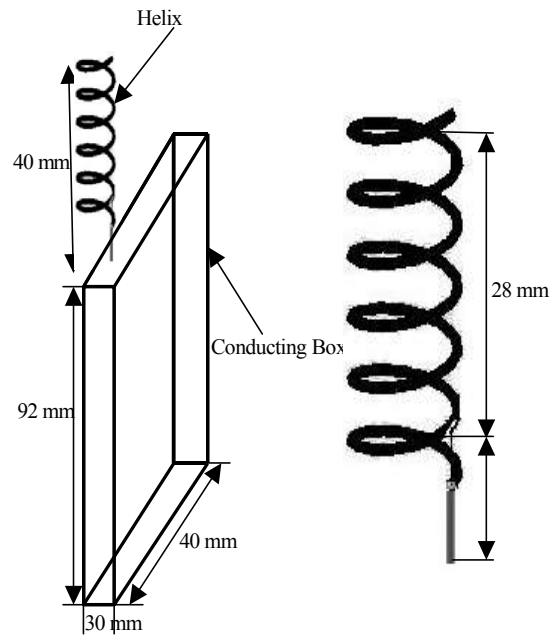
with external antennas. In [13], interaction of a single band helical antenna, mounted on a metallic box, with a human spherical head model has been investigated and reported. SAR level in head from a monopole, a helical and a PIFA antenna at 1.8-2.2 GHz has been computed and it has been shown that the PIFA antenna produces the lowest SAR in the head tissues [15-17]. For a helical antenna operating at 900 MHz, the SAR

Fig. 2: Helical antenna, adopted from literature with modifications [25]. The helix is fed with a 250-mW, 1.8-2.2 GHz source and the casing is used to define the ground. (a) Overall dimensions of the analyzed structure. (b) detailed dimensions of the helix radiating element.

quantity, radiation patterns and radiation efficiency in the presence of human head and hand has been computed [16, 18]. In another investigation, interaction of a dual band gap loop antenna with human head and hand has been investigated [17].
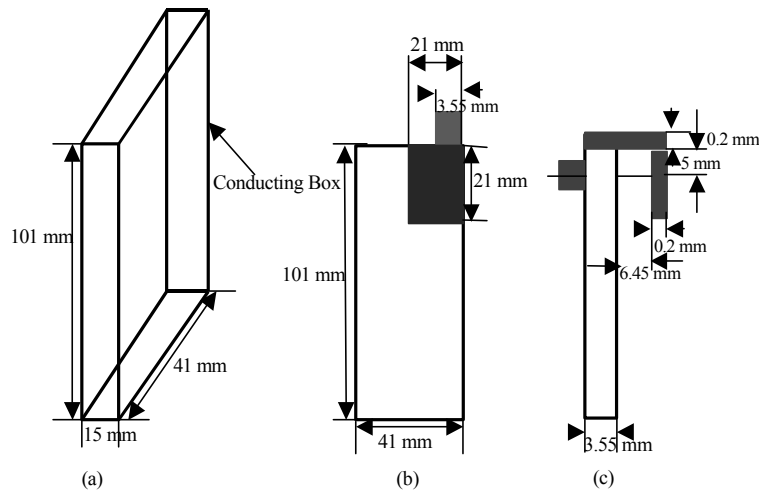

Fig. 3: Patch antenna-All dimensions in the sketch are given in millimeters. The antenna is a modified version on the antenna formerly reported in the literature [20]. (a) The overall telephone casing dimensions. (b) Broad-side view and (c) narrow-side view of the chassis and the patch. The chassis and the patch are embedded within the casing. The chassis is used to define the ground.
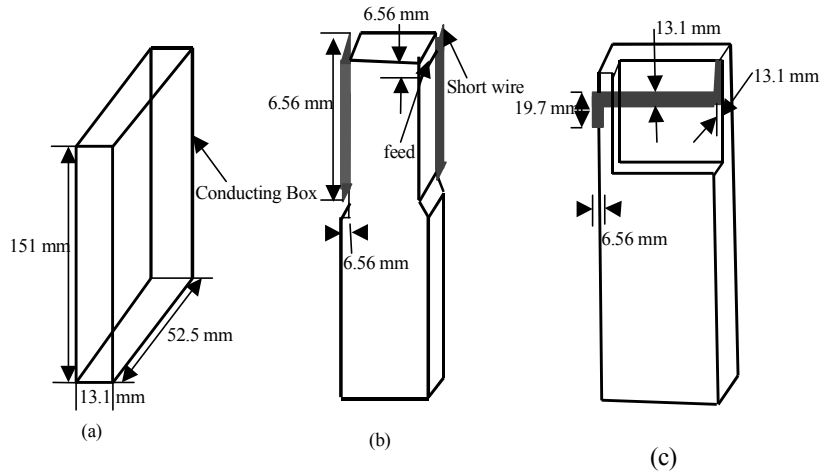
Fig. 4: PIFA antenna-All dimensions in the sketch are given in millimeters. The antenna is a modified version on the antenna formerly reported in the literature [10]. The overall telephone casing dimensions. (b) side-mounted dual PIFA and (c) back-mounted PIFA. The chasis dimensions (105 cm3) shown in (a) apply to all three configurations.

IEEE Standard 1528 and IEC 62209-1 specify protocols and process for the measurement of the peak spatial-average specific absorption rate (SAR) induced inside a simplified model of the head of the users of hand held radio transceivers (cellular phones). For example, the SAR limit specified in IEEE C95.1: 1999 is 1.6 W/Kg in a SAR 1 gm averaging mass while that specified in IEEE C 95.1: 2005 has been updated to 2 W/Kg in a 10 gm averaging mass. This new SAR limit specified in IEEE C 95.1: 2005 is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [1-2], [17-23]. Especially, the U.S. Federal Communication Commission (FCC) requires the routine SAR evaluation of phone model prior to device authorization or use since 1997.

It should be noted that similar studies have been reported, but with different antenna types, different antenna sizes, number of irradiated tissue types, different antenna frequency and lower spatial model used to simulate wave-tissue interaction [22-27].

The four types of antennas typically used in cellular telephones: monopole, helical, patch and PIFA antenna has been selected for this research. Antennas under investigation have different radiation patterns and hence result in different SAR levels in the head tissues. We compare the power deposition with respect to the SAR levels to determine the antenna that best complies with the safety standards. The following antennas are used in the simulation: monopole (Fig. 1), helical (Fig. 2) [25] and the patch (Fig. 3) [20].and PIFA (Fig. 4) [10]. All antennas were fed with a 250-mW continuous-waveform source at 1.8-2.2 GHz.

METHODOLOGY AND MATERIALS

Antenna radiation and its interaction with the head tissues were simulated with CST Microwave Studio (CST MWS), a three dimensional FDTD numerical tool. Complete handset model composed of the circuit board, LCD display, keypad, battery and housing was used for simulation. The relative permittivity and conductivity of individual components were set to comply with industrial standards. In addition, definitions in [20] were adopted for material parameters involved in the SAM phantom head. In order to accurately characterize the performance over broad frequency range, dispersive models for all the dielectrics were adopted during the simulation [22-23]. The electrical properties of materials used for simulation are listed in Table 1.

CST MWS, which adopted finite difference time-domain (FDTD) proposed by Weiland in 1976, was used as the main simulation instrument In permutation of the perfect boundary approximation (PBA) and thin sheet technique (TST), significant development in geometry

Table 1: Electrical properties of materials used for simulation

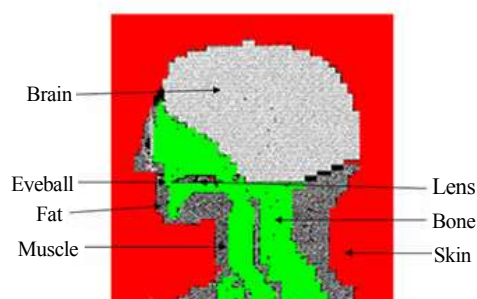| Phone Materials	ε_r	$\sigma(S/m)$
Circuit Board	4.4	0.05
Housing Plastic	2.5	0.005
LCD Display	3.0	0.02
Rubber	2.5	0.005
SAM Phantom Head		
Shell	3.7	0.0016
Liquid @ 900MHz	40	1.42

Fig. 5: The heterogeneous, realistic head model for FDTD

approximation with computation speed is achieved squashy highly accurate results. Non-uniform meshing scheme was adopted so that major computation endeavor was dedicated to regions along the inhomogeneous boundaries for fast and perfect analysis.

Fig. 5 shows a heterogeneous realistic head model for FDTD simulation. Numerical simulation of SAR value was performed by FDTD method. The parameters for FDTD computation were as follows. In our lossy-Drude simulation model, the domain were $128 \times 128 \times 128$ cells in FDTD method. The cell sizes were set as $\Delta x = \Delta y = \Delta z = 2.0$ mm. The computational domain was terminated with 8 cells perfect matched layer (PML). The antenna was designed such that the S_{11} response was less than-10 dB over the frequency band of interest. SAM phantom head was then included for SAR calculation using the standard definition as: [18].

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

where E is the induced electric field (V/m); ρ is the density of the tissue (kg/m³) and σ is the conductivity of the tissue (S/m). The resultant SAR values averaged over 1 gm and 10 gm of tissue in the head were denoted as SAR 1 gm and SAR 10 gm, respectively. These values were used as a benchmark to appraise the effectiveness in peak SAR reduction.

RESULTS AND DISCUSSION

The SAR levels for the head tissues are calculated for and with accordance to the two currently accepted standards: FCC and ICNIRP. Continuous waveform, representative of the sources used in mobile telephones, (250 mW, 1.8-2.2 GHz) is used as the form of the antenna excitation. Figs. 6-11 show SAR calculated within the tissues of the human head using the convention of the FCC standard [part (a) of each fig.] and the ICNIRP standard [part (b) of each fig.]. Each graph shows determined maximum average SAR for the volume relevant for the specified standard (1 gm for FCC and 10 gm for ICNIRP) of a particular head tissue as a function of antenna-head distance, for the distance of 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 mm separating the antenna and the head geometry. In Fig. 6, it is shown that there is a great influence of the distance between the antenna and human head on SAR reduction. If the distance between the antenna and the human head is increased from 0 to 20 mm, then the SAR value also decreases for monopole antenna, from 4.82 to 0.71 W/kg for SAR 10 gm
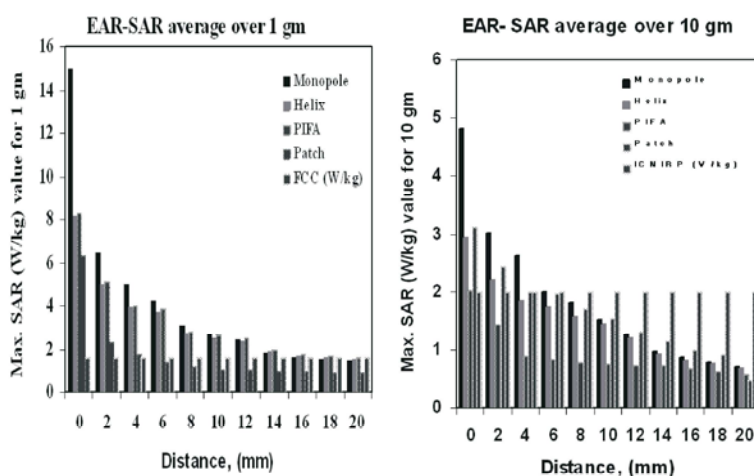

Fig. 6: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of ear tissue as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), helix (Fig. 2), patch (Fig. 3) and PIFA (Fig. 4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR <2 W/kg), are given in (a) and (b), respectively, for reference.
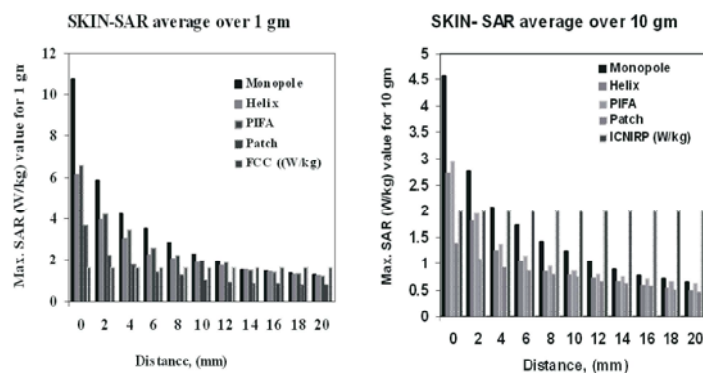
Fig. 7: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of skin tissue as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), helix (Fig. 2), patch (Fig. 3.) and PIFA (Fig. 4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR <2 W/kg), are given in (a) and (b), respectively, for reference.
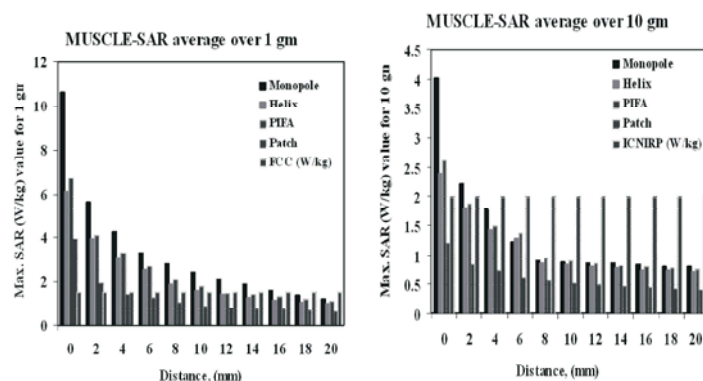

Fig. 8: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of muscle tissue as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), monopole-helix (Fig. 2), patch (Fig. 3.) and PIFA (Fig. 4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR <2 W/kg), are given in (a) and (b), respectively, for reference.
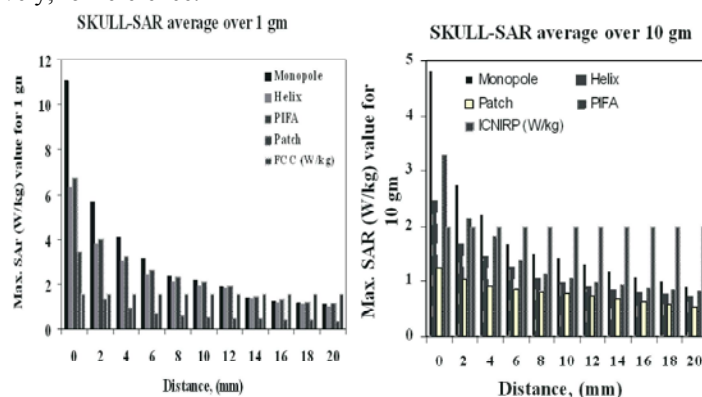

Fig. 9: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of skull tissue as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), monopole-helix (Fig. 2), patch (Fig. 3) and PIFA (Fig. 4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR <2 W/kg), are given in (a) and (b), respectively, for reference.

Fig. 10: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of brain tissue (grey matter) as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), helix (Fig. 2), patch (Fig. 3.) and PIFA (Fig.4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR <2 W/kg), are given in (a) and (b), respectively, for reference.
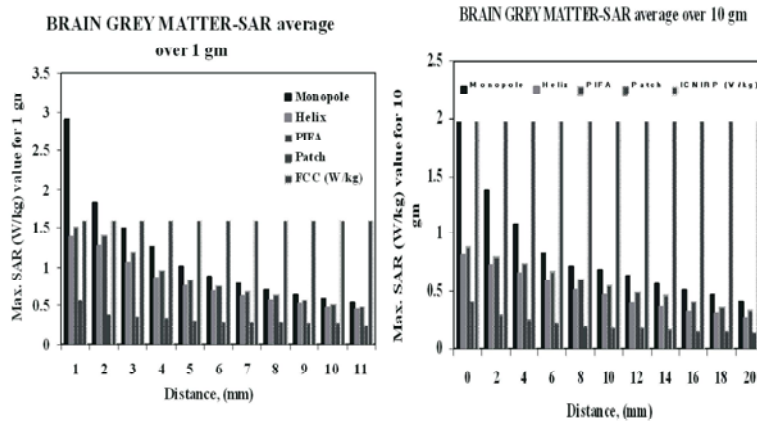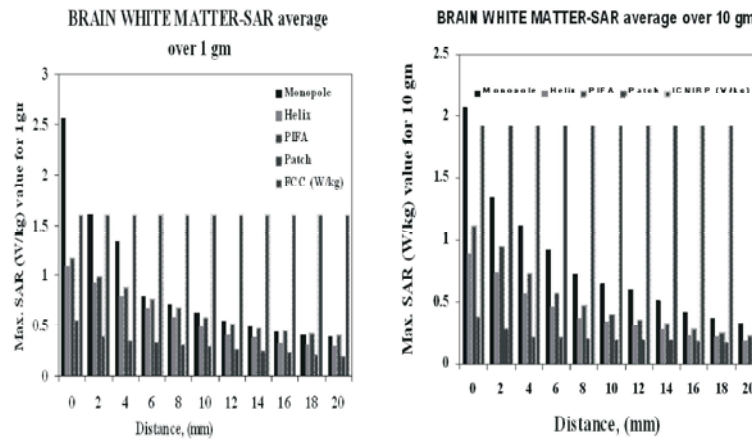

Fig. 11: Maximum SAR averaged over (a) 1 gm and (b) 10 gm of brain tissue (white matter) as a function of antenna-head distance. Results are shown for four antenna types under investigation: monopole (Fig. 1), helix (Fig. 2), patch (Fig. 3.) and PIFA (Fig. 4). Data were calculated for antenna-head distance of 0, 2, 4, 6, 8,10,12,14,16,18 and 20 mm. Safety standard levels determined by FCC (SAR <1.6 W/kg) and ICNIRP (SAR < 2 W/kg), are given in (a) and (b), respectively, for reference

and 14.96 to 1.45 W/kg for SAR 1 gm and also for helical antenna from 2.93 to 0.68 W/kg for SAR 10 gm respectively. It can be seen that for PIFA antenna from 2.02 to 0.58 W/kg and 8.31 to 1.61 W/kg for both cases of SAR 10 gm and SAR 1 gm also decreases. In this fig. it can be observed that the SAR value also decreases for patch antenna from 3.12 to 0.4 W/kg for SAR 10 gm and from 6.31 to 0.88 W/kg for SAR 1 gm. Results are shown for the following tissue types: ear (Fig. 6), skin (Fig. 7), muscle (Fig. 8), skull (Fig. 9), brain-grey matter (Fig. 10) and brain-white matter (Fig. 11). In all graphed results, we observe the expected falloff of the absorbed power with the increased antenna head distance. Nevertheless, with the antenna located very closely to the head, practically all four antenna types exceed the FCC standard within at least one of the tissues under investigation. In particular, the trend demonstrated in all graphs suggests that the monopole antenna is most likely to deposit higher power levels in the head tissues. In comparison, the SAR levels calculated for the patch antenna radiation show that this type of antenna best complies with the safety standards.

It should be noted that, as expected, the SAR levels differ from one tissue to another. Several factors contribute to this outcome. First, different tissues are located differently with respect to the antenna. Second, electric parameters vary among the tissues, which explicitly affects the SAR, [eqn. (1)]. Since the biochemical processes triggered by an elevated SAR level are

dependent on the tissue type (e.g. SAR of 2 W/kg does not carry identical consequences if it occurs in the brain or in the muscle), it is of essence that the power absorption be calculated and assessed for all head tissues separately.

Finally, we would like to stress the impact of the averaging volume (1 gm versus 10 gm) considered for SAR averaging. Figs. 6-11 quantify the fact that the ICNIRP more relaxed than the FCC standard. This, however, is not solely due to different absolute maximum SAR threshold values (1.6 W/kg for FCC and 2 W/kg for ICNIRP) but also due to the difference in the test volume of the tissue used for the SAR averaging. The larger volume used by the ICNIRP standard (10 gm) risks to obscure higher SAR values present in the tissue. The FCC standard uses a 1 gm tissue test volume and , as a result, detects local SAR peaks with better resolution when compared to the ICNIRP. This effect is analogous to the mathematical tools used in image processing to blur images containing visible, sharp contrasts: if the "patch" used for averaging that scans over the image is larger, the more blurred is the resulting processed image.

CONCLUSIONS

The comparative study of a monopole, a helical, a patch and a PIFA antenna at 1.8-2.2 GHz has been presented in this paper. When the antenna is very close to the human head, all antennas types under study deposit in the near-surface tissues of the head power levels that exceed the FCC standard. The monopole antenna yields the highest SAR levels in all tissues, while the patch is most likely to meet the safety standard. Due to different location with respect to the radiating antenna and different conductivities, not all the tissues experience the same power absorption. SAR must be calculated and averaged separately for each identified tissue volume for accurate and significant assessment of potential risky implications of the absorbed radiated power.

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