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A Study Of EMR And SAR Distribution In Human Head Phantom Exposed To RF Energy: A Simulation Approach.

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Abstract

In this study, the radiated emission field and specific absorption rate (SAR) when a human head phantom was exposed to radio frequency (RF) field of a mobile phone model was carried out and conducted using the FEKO emss software. The radio frequencies considered for this work were the 900MHz and the 1800MHz as used by the global system for mobile communication in Nigeria. The human head model and a mobile phone model were developed with the aid of an Electromagnetic Simulation Software (emss) known as FEKO. The phone simulated was positioned in the calling mode such that the radiation mainly focuses on the head, and the simulated results as displayed on the FEKO emss GUI window were presented. The solution of the simulation in terms of the internal electric field and SAR distribution in the head were interpreted in both the x-direction and y-direction. The E-field taken in the x-direction (plane) of the simulated result measured the highest values around the core area of the head with a magnitude of about 12.5V/m and 10.5V/m at 900MHz and 1800MHz respectively. Around the ear, the SAR values were 0.33W/kg and 0.417W/kg at 900MHz and 1800MHz respectively. The magnitude of SAR of about 0.0317W/kg was measured around the core area of the head as viewed in the x-direction within 6.48hours simulated time of RF exposure to the head phantom. However, the spatial-peak SAR values as averaged over 1 gram and 10g on the human head model obtained with a radiated power of 0.32W for both simulations were well below the limit of 1.6 W/kg of ICNIRP standard and FCC/IEEE standard of 2W/kg.

Keywords: Electromagnetic radiation (EMR), Specific Absorption Rate (SAR), Electromagnetic simulation software (FEKO emss), Radio frequency field, human head, mobile phone, mobile phone antenna, spatial peak SAR.

1. Introduction:

Cellular telephony or mobile communication is one of the fastest growing and most demanding technology today in Nigeria [1]. This growth indicates a continuous increasing percentage of telephone subscribers around the world [2]. According to the Nigeria statistics accessed in 2010, the number of mobile phone users as at 2008 was 62,988,492.0. And as at 2009, Nigerian was ranked number thirteen in the world with a total number of 76,000,000 phones in use. According to the International Telecommunication Union (ITU), mobile phone users will increase despite the global economy slump. This means that the use of mobile handset is on the increase by the day.

Cell phones contain both radio receiver and transmitter. The transmitter generates a radio frequency (RF) field around the cellular phone. RF fields are non-ionizing radiations (NIR). However, their fields between 1 MHz and 10 GHz penetrate exposed tissues and produce heating due to energy absorption in these tissues. The depth of penetration of the RF field into the tissue depends on the frequency of the field and is greater for lower frequencies. Energy absorbed from RF fields in tissues is measured as a specific absorption rate (SAR) within a given tissue mass. The unit of SAR is watts per kilogram (W/kg)[3]. An SAR of at least 4 W/kg is needed to produce adverse health effects in people exposed to RF fields in this frequency range. Most adverse health effects that could occur from exposure to RF fields between 1 MHz and 10 GHz are consistent with responses to induced heating, resulting in rises in tissue or body temperatures higher than 1C. [4,5].

However, since mobile phones are used in close proximity to the human body, there is call for concern if the RF fields around the phone do cause such negative effects on the user. This is a worrisome issue in the minds of phone users in Nigeria, since most hand phones in use produce induced heating effect after a maximum of 5minutes; either receiving or transmitting. Are users safe with the phone constantly close to their body or in their pockets with close contact to the body? Do RF fields have sufficient energy to penetrate exposed tissue? Are the phones in use in Nigeria functioning within the limits of the recommended (1.6W/kg and 2.0W/kg) SAR limits? Is there any SAR limit specified by the Nigeria Communication Commission (NCC)? The benefits of cellular phones usage in Nigeria as well as anywhere in the world are enormous, but the society still believes that they may present a long-term health risk, even though the world health organization (WHO) disputes this assertion in their mobile phone usage recommendations in 2010 [6]. Certain countries, however, including France, India, have warned against the use of cell phones especially by minors due to health risk uncertainties [7].

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Thus, in this paper we present a study on the electromagnetic radiation (EMR) in terms of the electric field distribution, and SAR distribution within a human head phantom when a mobile phone is placed close (in receiving position) to the ear. This paper is not suggesting that cell phone use is harmful to health. However, recommendations presented from this study are suggesting possible ways to stay safe with the use of cell phone.

BACKGROUND LITERATURE

Cellular phones are electronic devices that communicate with the cellular system base station. The most modern telephone is the cellular telephone, or commonly called a cell phone or hand phone or handset [8]. A cell phone is a radio telephone that may be used wherever "cell" coverage is provided. A cellular telephone is designed to give the user maximum freedom of movement while in use. Although cell phones usages are always confined to a limited range, their provision for roaming and handover makes communication easy within a global environment. Cellular/mobile phones are everywhere and their utility is growing. Mobile phones are used for a variety of purposes including keeping in touch with family members, conducting business, and for emergency. Some people carry more than one cell phone for different reasons; personal or business.

The cellular phones are devices that communicate constantly with a serving base station whether the device is in idle mode or active mode. Thus from time to time there are radiated emissions around the phone. The electromagnetic field or radiation, emitted from the phone is invisible to the human eyes, and it characteristics defers as a function of frequency and wavelength. The human body interact with this field, and some of the radiation from the phone because of its proximity to the user, is absorbed by the body when exposed to it. The effects of electromagnetic fields on the human body depend not only on their field level but on their frequency and energy. Thus, a measure of the rate at which this energy is absorbed by the human body tissue when exposed to the radio frequency (RF) electromagnetic field is called specific absorption rate (SAR). [9] According to the Institute of Electrical and Electronics Engineers (IEEE), SAR is the time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of a given density [5]. According to ANSI, SAR is the time rate at which radio frequency electromagnetic energy is imparted to an element or mass of a biological body [5]. SAR is expressed as energy flow (power) per unit of mass in units of W/kg'.

SAR is used to measure exposure to fields between 100 kHz and 10 GHz. [10] It is commonly used to measure power absorbed from mobile phones. Its value will depends heavily on the geometry of the part of the body that is exposed to the RF energy and on the exact location and geometry of the RF source. Thus tests must be made with each specific source, such as a mobile phone model, and at the intended position of use. For example, when measuring the SAR due to a mobile phone the phone is placed at the head in a talk position. The SAR value is then measured at the location that has the highest absorption rate in the entire head, which in the case of a mobile phone is often as close to the phone's antenna as possible. SAR is usually averaged either over the whole body, or over a small sample volume (typically 1 g or 10 g of tissue). The value cited is then the maximum level measured in the body part studied over the stated volume or mass. [9]. Local SAR is determined over a mass of 10 g. It can be calculated from the electric field within the tissue as: [5, 11].

$$\mathrm{SAR} = \int_{\mathrm{sample}} \frac{\sigma(\mathbf{r})\,|\mathbf{E}(\mathbf{r})|^2}{\rho(\mathbf{r})}\,d\mathbf{r} \tag{1}$$

Where; σ is the sample electrical conductivity, *E* is the RMS electric field, ρ is the sample density.
SAR can also be expressed as: [12]

$$SAR = \frac{P_r}{M} \tag{2}$$

Where; *Pr is* the power absorbed by human body measured in Watts (W), *M* is the weight/mass of the absorbing radiation part of human body measured in kilogram (kg).

Although RF fields are non-ionizing, it still penetrates exposed tissues to depths that depend on the frequency of operation - at the frequencies used by mobile phones. RF energy absorbed in the body produces heat. Hence, all established health effects of RF exposure are clearly related to heating. While some researchers have noted that RF energy can interact with body tissues at levels too low to cause any significant heating, exposure to low-levels of RF fields, too low to produce heating, has been reported to alter the electrical activity of the brain in cats and rabbits by changing calcium ion mobility. Scientists have also reported other effects of using mobile phones including changes in brain activity, reaction times, and sleep patterns. According to [13], people who use mobile phones regularly may be putting themselves at risk of developing a delibilitating ear condition. Regular use is defined as 10 minutes per day by the researchers. A small study published suggested that the use of mobile phones for at least four years was linked to a doubling in the risk of developing chronic tinnitus, a persistent ringing or hissing in the ear [4].

In view of the danger associated with the use of mobile phones as mentioned above, rather than specify the emission limits, various governments has defined safety limits for exposure to RF energy produced by mobile devices. The SAR limit for all mobile phones sold in Australia, USA is 1.6 watts per kilogram of tissue (averaged over 1 gram). In Europe, the European

Union Council adopted the recommendations made by the International Commission on Non-Ionising Radiation Protection (ICNIRP Guidelines 1998), and recommended SAR limit of **2.0 W/kg** averaged over 10g of tissue. Hence any cell phone at or below these SAR levels (that is, any phone legally sold in the U.S, or Europe.) is a "safe" phone, as measured by these standards. The Federal Communications Commission (FCC) SAR limit is also 1.6 W/kg in 1g of tissue. SAR limits for occupational exposures are also outlined in [14, 15].

The goal of this study is to determine the extent of the internal electric field and the SAR distribution inside the head of an arbitrary man exposed to RF fields from a mobile handset. A homogeneous head phantom was assigned for the frequency of 900MHz and 1800MHz. The investigation is based on computer simulation method using the FEKO electromagnetic simulation software (emss) [16].

METHODOLOGY

The method employed simulate a head model and mobile phone model using electromagnetic simulation software called FEKO emss, and hence evaluate the internal electric field as well as the SAR distribution in the human head model exposed to the radio frequency field of a mobile phone. The simulation was carried out for GSM frequency 900MHz and 1800MHz. The program FEKO is based on the principles of Method *of Moments* (MoM).

On the FEKO emss GUI interface, the procedures followed in the simulation includes; Defining Variables: this involves entering the parameters needed for the simulation. These parameters includes frequency range of the antenna, Radius of the antenna in use, Radiated power of the antenna, relative permeability, conductivity and mass density of muscle tissues of human body under consideration (head). The next step is to create the homogeneous human head model which was done using the CADFEKO tool of the emss program based on the defined parameters. Although a heterogeneous head structure would have been more realistic, yet more difficult to implement, thus a homogeneous head structure was developed. The SAR averaging mass was then input in the solution request dialog box. This dialog box request for volume and Spatial peak SAR value over 1g, and 10g of tissue, as recommended by FCC/ICNIRP standard for SAR determination. Once the design of the models was done, running the simulation proper was the next stage. This was achieved with the sub program RUN FEKO solution.

Using the European Committee for Electrotechnical Standardization (CENELEC) and the Institute of Electrical Electronic Engineering (IEEE) standard for the dielectric properties of head tissue-equivalent material [17, 18] as a guide, and the dielectric properties of the body parts that can be expose to EM radiation as in [19], we choose the values of the dielectric properties similar to those of the human head phantom for this simulation as shown in Table 1. This Table described the human head tissue in terms of its mass (kg), relative permeability, and conductivity of the head tissue. For the mobile phone simulation at 900MHz and 1800MHz which is the GSM operating frequency as at the time of this study in Nigeria, the parameters used are tabulated in Table 2.

The preprocessor/mesher PREFEKO tool of the EM simulation software processes this file (and prepares the input file (.fek) for the program FEKO which is the actual field calculation code. PREFEKO enables the user to create complex geometries with a single command, e.g coils consisting of wire segments, or flat, cylindrical or spherical plates consisting of triangles. Using the software tools require no knowledge of the mathematics behind the MOM. However, the simulation information including the amount of time used to run each simulation, and the amount of memory space used up are presented in Table 3. The solution of the simulation was viewed using the POSTFEKO feature of the program.

The simulation results presented with the head shifted in two direction; x-direction and y-direction to view the extent of the field distribution are shown in Figures 1 – 8.

Table 1: Target dielectric properties of head tissue-equivalent material

Properties of Tissues	Dielectric Permittivity (□$_r$)	Conductivity σ (S/m)	Mass Density ρ (kg/m^3)
900MHz	45.8	0.77	1030
1800MHz	43.5	1.15	1030

Table 2: Simulation Parameters/Variables used for the mobile phone

PARAMETERS	Simulation 1 (900MHz)	Simulation 2 (1800MHz)
Frequency	900 MHz	1800MHz
Antenna Radius	0.0025m	0.0012m
Radiated Power of Antenna	0.32watts	0.32watts
Averaging Mass of tissue	1g and10g	1g and 10g

Table 3: Computation Information from the Simulation in FEKO program

FEKO Program	900MHz	1800MHz
The total computation surface	9 wire segments 188 metallic triangles 1480 dielectric triangles	9 wire segments 502 metallic triangles 2868 dielectric triangles
Total number of basis function	4730 unknowns	9365 unknowns
Method of moment Matrix	4736 rows * 4730 columns = 22401280 complex numbers	9376 rows * 9365 columns = 87806240 complex numbers
Memory Required on disc	341.383 Mbytes	1.307 Gbytes
Total time	6.48 hours	12.67 hours

RESULTS

The simulation result obtained with the mobile phone model in the calling position viewed in the x- and y- direction as displayed on the emss GUI window are shown in Figures 1 - 8.

Numerical results for the average SAR and spatial-peak specific absorption rate in W/kg obtained for 1gram and 10 grams tissue at 900MHz and 1800MHz computed with the software are presented in Table 4.

Table 4: Average SAR and Spatial-Peak SAR in W/kg for (1gram and 10 grams) tissue at 900MHz and 1800MHz.

SAR	Average SAR	1g-SAR_{max} (W/kg)	10g-SAR_{max} (W/kg)
900 MHz	0.029081	0.4221153	0.3337675
1800 MHz	0.013005	0.8290554	0.5431772

Using the colour legend of Figures 1-8, the numerical values of SAR and E-field distribution as interpreted from the figures in the x and y plane are presented in Table 5. These values were taken at the location that has the highest absorption rate and highest E-field distribution in the entire head. The information in Tables 4 and 5 in terms of average SAR and the local SAR (spatial peak SAR averaged over 10g of tissue) are in agreement depicting a high degree of simulation accuracy.

Table 5: Numerical data obtained from Figures 1- 8.

Frequency of operation	Average SAR (W/kg)	SAR averaged over 10g (W/kg)	E-field in x-direction (V/m)	E-field in y-direction (V/m)
900MHz	0.0317	0.33	12.5	30.468
1800MHz	0.0128	0.417	10.5	30.167

DISCUSSIONS/FINDINGS

Figures 1 and 2 show the distributions of the internal electric fields in the x-plane for 900 and 1800 MHz measured in volt/meter, while Figures 5 and 6 show the distributions of the internal electric fields in the y-plane for 900 and 1800 MHz measured in volt/meter. Figures 3, 4, 7 and 8, show the result of the simulation pattern of the SAR distribution in the x, and y-directions at 900MHz and 1800MHz respectively.

The colour codes in the figures represent description of internal electric field and Local SAR distribution in the head model produced by the radiating antenna from the simulation. The magnitude of the distribution presented alongside the figure legend, is represented in different colours. The magnitude of the values is a representation of the penetration level of the internal electric field.

In Figure 1 and 2, the highest values of the magnitude of E-field distribution taken along the y-direction (plane) were about 30.468V/m and 30.167V/m at 900MHz and 1800MHz respectively. This means that in the calling position considered in this study, the field was more near the human ear as observed in the figures. The E-field taken in the x-direction (plane) of the simulated result as shown in Figures 5 and 6, measured the highest values in the core area of the head (which may be around the brain) with magnitude of about 12.5V/m and 10.5V/m at 900MHz and 1800MHz respectively. Around the ear, the SAR values were 0.33W/kg and 0.417W/kg at 900MHz and 1800MHz respectively. This shows that as the frequency increases, the amount of RF energy absorbed around the ear tissues were more as seen in Figures 3 and 4. And within the simulated time if these values were recorded, then over time with the continuous use of the phone (depending on its designed parameters), the claim of the risk of developing chronic tinnitus, a persistent ringing or hissing in the ear [4], might be a possibility. In Figure 7, the magnitude of SAR of about 0.0317W/kg was observed around the core area of the head as viewed in the x-direction within

6.48hours simulated time of RF exposure to the head phantom. Thus with continuous use of the phone (depending on the designed parameters of the head and the phone), the claim that using the mobile phone can alter or cause changes in brain activity, may also be a possibility.

FINDINGS

The simulated result of the human head phantom exposed to RF energy from the mobile phone model shows that at radio frequency, the energy emitted is sufficient to penetrate human tissues as seen in Figure 1 – 8. The obtained results in Table 4 show that the spatial-peak SAR values as averaged over 1 gram and 10g in the head model obtained with a radiated power of 0.32W for both simulations were well below the limit of 1.6 W/kg of ICNIRP standard and FCC/IEEE standard of 2W/kg. The spatial-peak SAR values for 1gram and 10 grams from Table 4 at 1800MHz are higher than those for 900MHz. The SAR is inversely proportional to the mass/ weight of the body under consideration. Thus, in Table 4, the amount of energy absorbed over the 1g tissue is higher than that over the 10g tissue. The SAR regions produced by 900MHz antenna are more extended as compared to those induced by 1800 MHz antenna as seen in Figures 1 - 4; this explains why the average SAR, over human head, at 1800MHz is less than that at 900MHz. The magnitude of the E-field generated is directly proportional to the SAR as in equation 1, hence as the magnitude increase in either direction, SAR increases as shown in Table 5.

CONCLUSION

The research with simulations approach gave very valuable information about the SAR distribution within the human head phantom and the mobile phone in a calling position. The result obtained with the FEKO electromagnetic simulation software showed that the average SAR value at 900MHz and 1800MHz simulated within an average time of 6.48 and 12.67 hours respectively are well within the limit of the standard values. The simulation result shows that the spatial peak SAR produced at 900MHz averaged over the body weight of 1g and 10g tissue was lower than that at 1800MHz. The SAR values are still within the limit of the FCC, IEEE, and ICINRP recommended standards. Although these values at the different frequencies considered in the study fall within these limits, continuous exposure to this radiating device could cause adverse health effect on the users of the device, since it is evident that RF energy penetrates exposed tissues, and the amount of energy absorbed is a function of frequency and its intensity, and the depth of penetration of the RF field into the tissue also depends on the frequency of the field and is greater for lower frequencies. This study reveals that there could be possible health risk with continuous exposure to the RF fields. Hence, the authors call on the Nigerian Communications Commission (NCC), and the Standard Organization of Nigeria (SON) to ensure that all mobile handsets sold in country, functions below its maximum permissible SAR values specified. Manufacturers should develop mobile communication devices with low radiating power to avoid electromagnetic pollution. Users of mobile phones should avoid staying long on calls (not longer 10 minutes per day) [13]. They should also avoid carrying handsets in their pockets to reduce RF exposure level. However, cell phones should be kept at some distance from the human body when not in use.

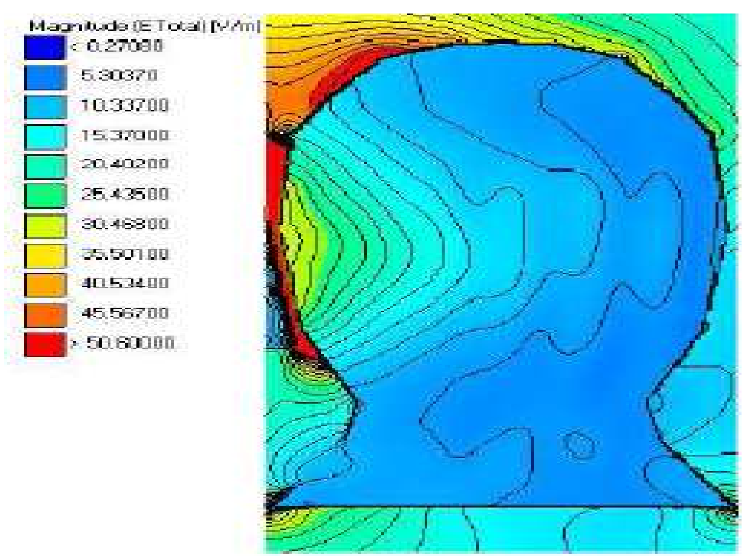


Fig. 1: Internal Electric field in y-direction at 900MHz

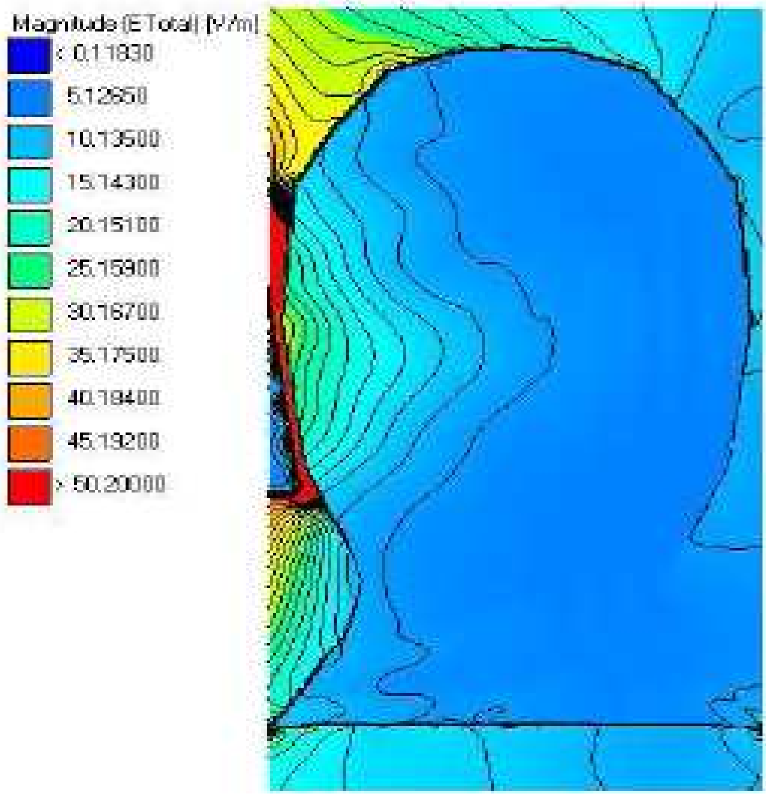


Fig. 2: Internal electric field in y-direction at 1800MHz

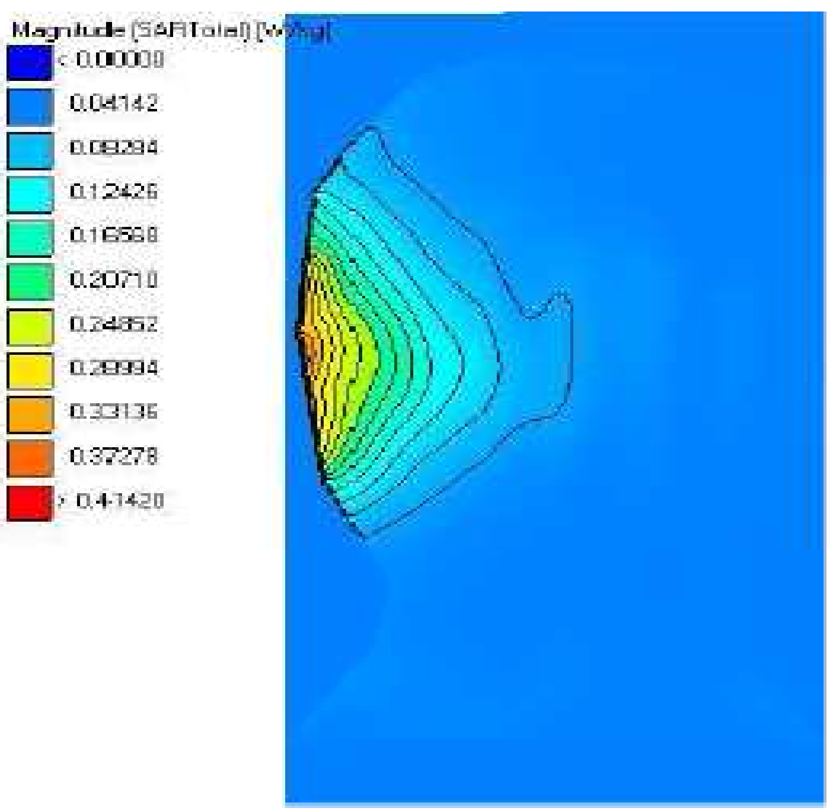


Fig. 3: SAR distribution in y-direction at 900MHz

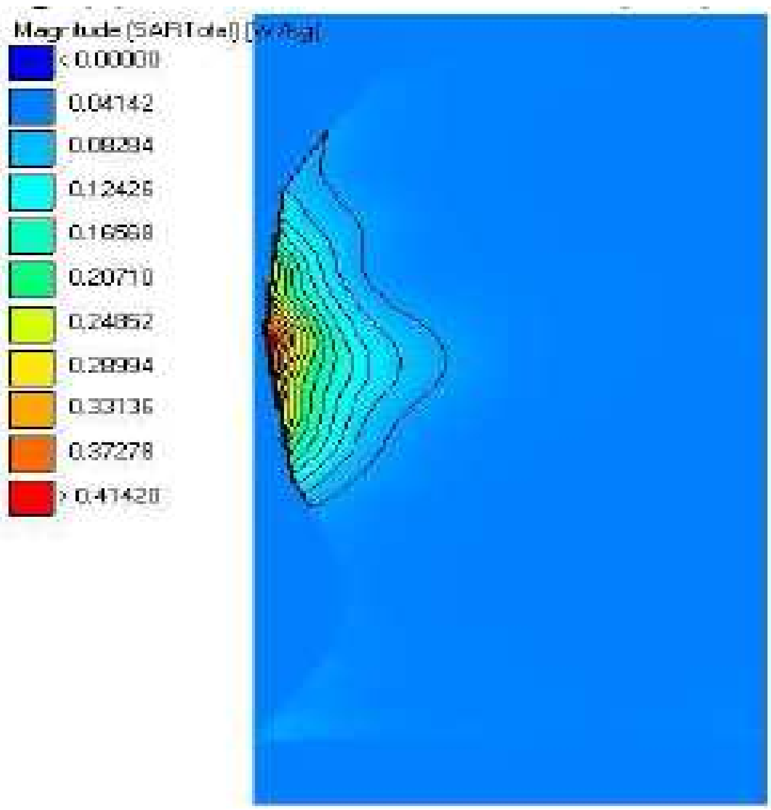


Fig.4 : SAR distribution in y-direction at 1800MHz

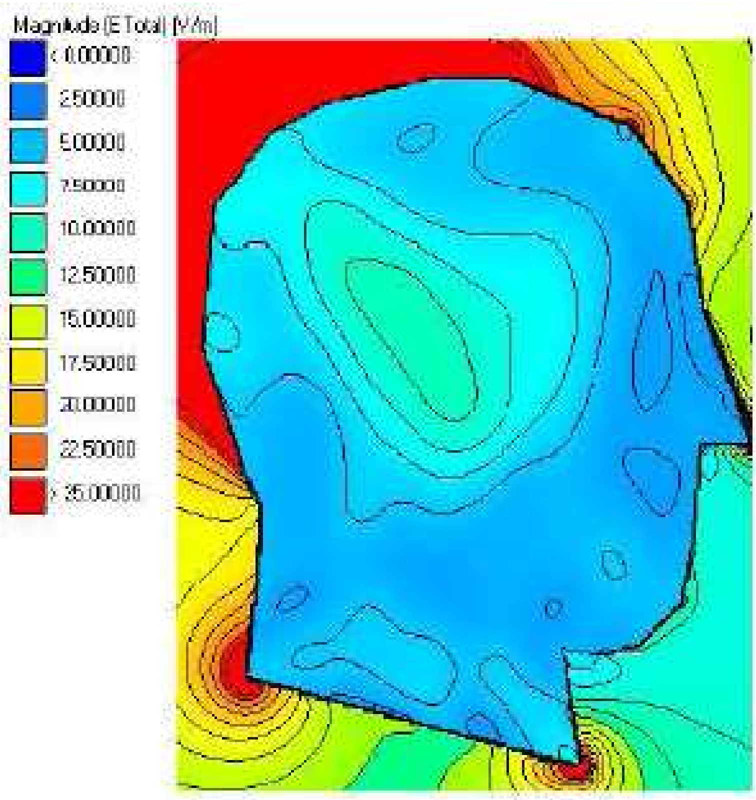


Fig. 5: Internal Electric field in x-direction at 900MHz

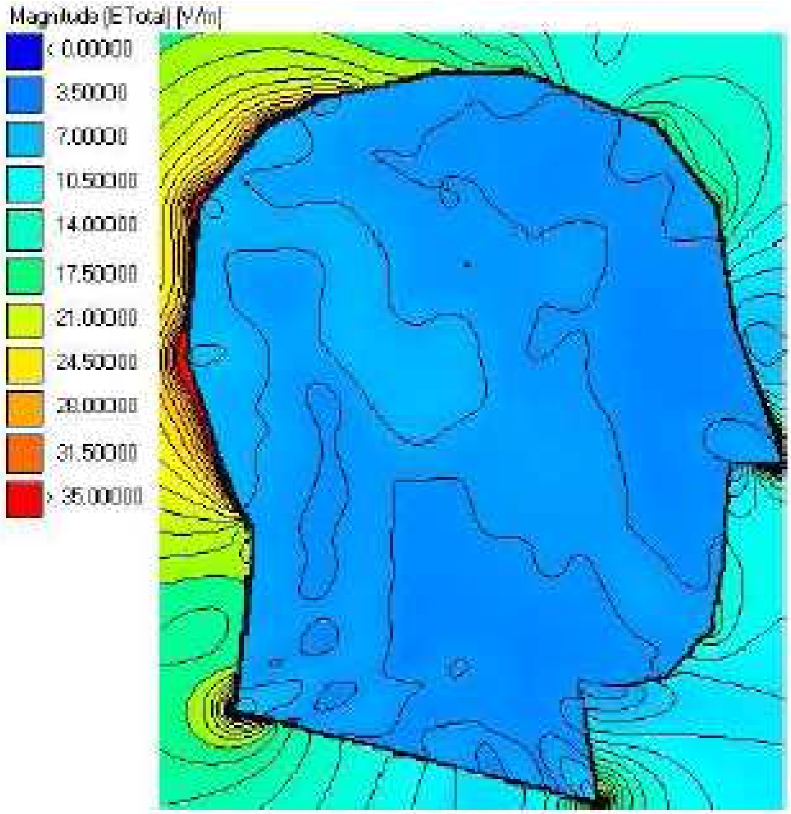


Fig. 6: Internal Electric field in x- direction at 1800M

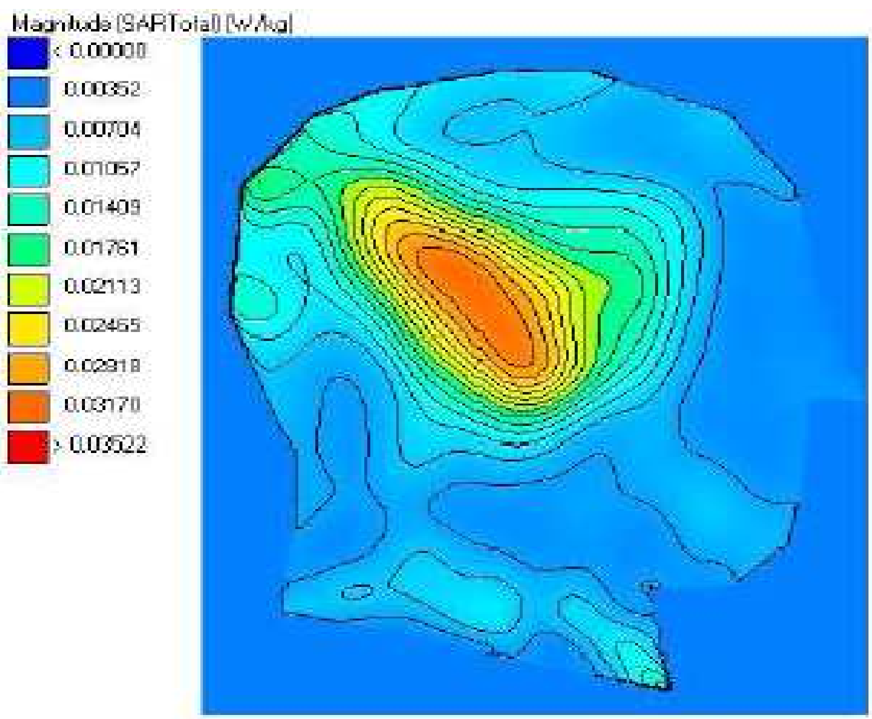
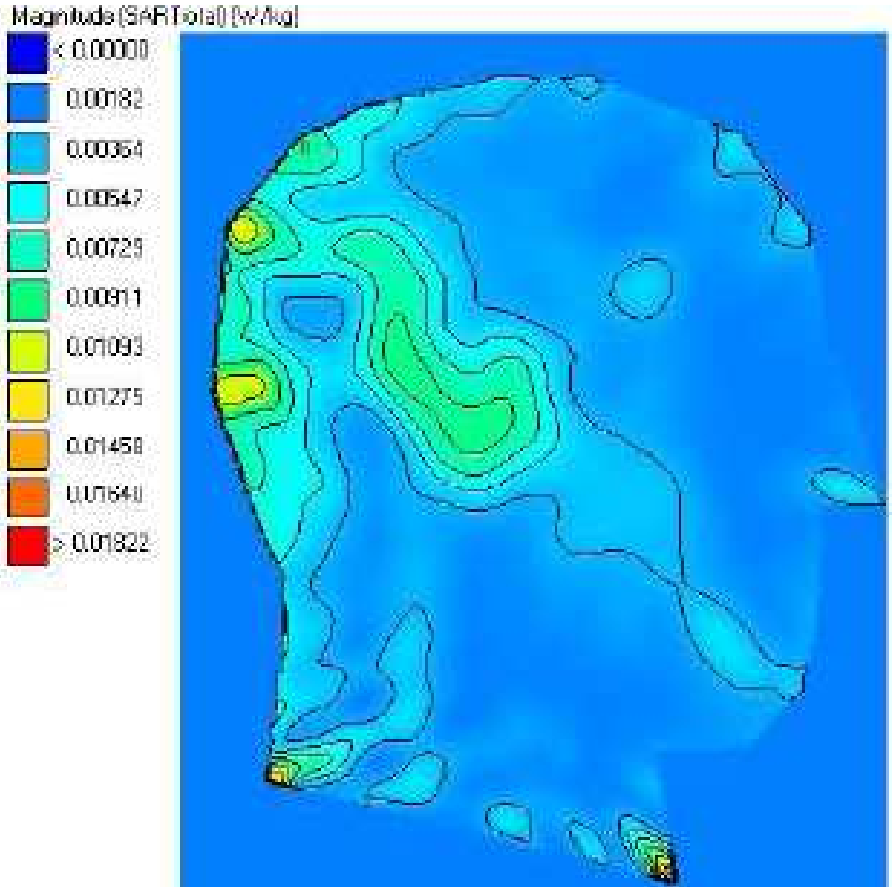


Fig. 7: SAR distribution in x-direction at 900MHz



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