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REDUCTION OF SPECIFIC ABSORPTION RATE (SAR) IN THE HUMAN HEAD WITH FERRITE MATERIAL AND METAMATERIAL

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Abstract—The electromagnetic interface between the antenna and the human head is reduced with ferrite materials and metamaterials. The reduction of Specific Absorption Rate (SAR) with materials and metamaterials is performed by the finite-difference time-domain method with Lossy-Drude model by CST Microwave Studio. The metamaterials can be achieved by arranging split ring resonators (SRRs) periodically. The SAR value has been observed by varying the distances between head model to phone model, different widths, different thicknesses, and different heights of materials and metamaterial design. Materials have achieved 47.68% reduction of the initial SAR value while metamaterials achieved a reduction of 42.12%. These results can endow with supportive information in designing the wireless communications equipments for safety compliance.

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1. INTRODUCTION

The possible health risk of mobile communication handset due to its electromagnetic (EM) interface with human and the means of reducing the impact of this interface have appeared as a general concern. Many factors may affect the EM interaction while using cellular handset in close proximity to head and hand. The specific absorption rate (SAR) is a defined figure of merit to evaluate the power absorbed by biological tissue. For the cellular phone compliance, the SAR value must not exceed the exposure guidelines [1, 2]. 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 C95.1 : 2005 has been updated to 2 W/Kg in a 10 gm averaging mass [1]. 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 [2]. In general, the SAR value is influenced by various parameters such as antenna positions relative to the human body, radiation patterns of the antenna, radiated power and antenna types [3].

Over the last fifteen years, many authors have investigated the SAR with human head due to the complexity and large scale involved in such kinds of problems [4–12]. Recently, lots of attentions have been paid to the reduction of peak SAR within materials and metamaterials. In [5], a ferrite sheet was adopted as protection attachment between the antenna and the human head. A reduction over 13% for the spatial peak SAR over 1 gm averaging was achieved. Study on the effects of attaching materials and metamaterials for SAR reduction was presented [12], and it was concluded that the position of shielding played an important role in the reduction effectiveness. Metamaterials composed of an array of split ring resonators (SRRS) were applied to the reduction of SAR [11]. With proper design and arrangement, stop bands at desired mobile frequencies can be achieved.

In [13], for the SAR in human head, an effective approach is the use of a planar antenna integrated onto the back side (away from the head) of a phone model, but it brings additional design difficulties especially in achieving the required frequency bandwidth and radiation efficiency. Another approach is the use of a directional or reflectional antenna [14, 15]. Such an antenna structure sacrifices the availability of signals received from all directions to the phone model. The mechanism of SAR reduction by ferrite sheet attachment was due to the suppression of surface currents on the front side of phone model [16]. However, the relationship between the maximum SAR reducing effect and the parameters such as attaching location, size and material properties of ferrite sheet remains unknown.

In [17], a perfect electric conductor (PEC) reflector was arranged between a human head and the driver of a folded loop antenna. The result showed that the radiation efficiency can be enhanced and the peak SAR value can be reduced. In [18], a study on the effects of attaching conductive materials to cellular phone for SAR reduction has been presented. It is indicated that the position of the shielding material is an important factor for SAR reduction effectiveness. There is a necessity to make an effort for reducing the spatial peak SAR in the design stage of material and metamaterials because the possibility of a spatial peak SAR exceeding the recommended exposure limit cannot be completely ruled out.

Materials and metamaterials have inspired great interests due to their unique physical properties and novel application [11, 19]. The motivation of this paper is to design metamaterials to investigate a potential reduction of the peak SAR value compared with the research by Hwang and Cheng [11]. Metamaterials denote artificially constructed materials having electromagnetic properties not generally found in nature. Two important parameters, electric permittivity and magnetic permeability, determine the response of the materials to the electromagnetic propagation. The negative permittivity can be obtained by arranging the metallic thin wires periodically. On the other hand, an array of SRRS can exhibit negative effective permeability. The designed SRRS operated at 900 MHz were used to reduce the SAR value in a lossy material.

In this paper, materials are placed between antenna and a human head then replaced to metamaterial. In order to study SAR reduction of antenna operated at the GSM 900 band, the effective medium parameter of metamaterials is set to negative at 900 MHz. Different positions, sizes, and negative medium parameters of materials and metamaterials for SAR reduction effectiveness are also analyzed by using the finite-difference time-domain (FDTD) method in conjunction with a detailed human head model. The results lead to a guide to choosing and designing the ferrite sheet with the largest SAR reducing effect. In this paper, SAR is reduced by two methods, namely, using a natural electromagnet absorbing material (ferrite material) and an artificial constructed material (metamaterial).

2. SAR REDUCTION BY FDTD METHOD WITH LOSSY DRUDE MODEL

2.1. FDTD Method with Lossy-Drude Model

The SAR reduction effectiveness and antenna performance with different positions, sizes and negative medium parameters of materials and metamaterials will be analyzed. The head models used in this study was obtained from MRI-based head model through the whole brain Atlas website. Six types of tissues, i.e., bone, brain, muscle, eye ball, fat, and skin were involved in this model [20–22]. Figure 1 shows a horizontal cross-section through the eyes of this head model. The electrical properties of tissues were taken from [3, 17].

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 $\Delta x = \Delta y = \Delta z = 1.0\,\text{mm}$. The computational domain was terminated with 8 cells PML. A helix antenna was modeled for this paper by thin-wire approximation. Simulations of materials and metamaterials are performed by FDTD method with Lossy-Drude Model. The method is utilized to understand the wave propagation characteristics of materials and metamaterials.

2.2. SAR Calculation in the Head with Materials

Figure 2 shows the simulation model which includes the handset with monopole type of helix antenna and the SAM phantom head that provided by CST Microwave Studio® (CST MWS) [16]. Complete

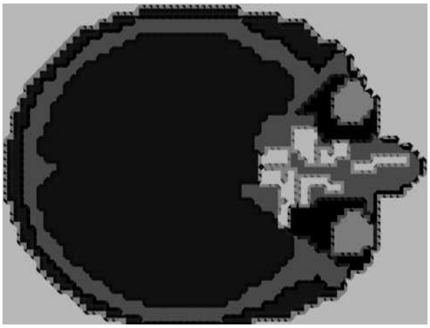

Figure 1. Human head model for FDTD computation.

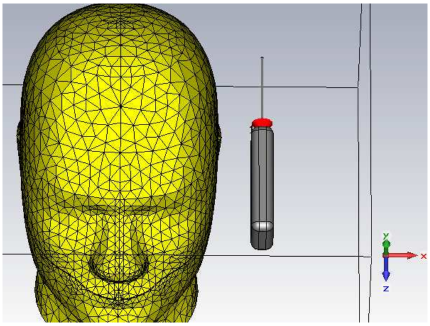

Figure 2. The head and antenna models for SAR calculation.

handset model composed of the circuit board, LCD display, keypad, battery and housing was used for simulation. The relative permittivity and the conductivity of individual components were set to comply with industrial standards. The dispersive models for all the dielectrics were adopted during the simulation in order to accurately characterize the materials and metamaterials. The antenna was arranged in parallel to the head axis; the distance is varied from 5 mm to 20 mm; and finally 20 mm was chosen for comparison with materials and metamaterials.

Besides that, the output power of the cellular phone model need to be set before SAR is simulated. In this project, the output power of the cellular phone is 500 mW at the operating frequency of 0.9 GHz. In the real case, output power of the cellular phone will not exceed 250 mW for normal use, while the maximum output power can reach till 1 W or 2 W when the base station is far away from the mobile station (cellular phone).

The SAR simulation is compared with the results in [3, 4] for validation, as shown in Table 1. The calculated peak $\mathrm{SAR}_{1\,\mathrm{gm}}$ value is 2.002 W/Kg, and $\mathrm{SAR}_{10\,\mathrm{gm}}$ value is 1.293 W/Kg when the phone model is placed 20 mm away from the human head model without materials. This SAR value we achieved is better compared with the result reported in [11], which is 2.43 W/Kg for $\mathrm{SAR}_{1\,\mathrm{gm}}$. The ferrite sheet material is utilized in between the phone and head models, and it is found that the simulated value of $\mathrm{SAR}_{1\,\mathrm{gm}}$ and $\mathrm{SAR}_{10\,\mathrm{gm}}$ are 1.043 W/Kg and 0.676 W/Kg respectively. The reduction about 47.68% was observed in this study when a ferrite sheet is attached between phone and human head models for $\mathrm{SAR}_{1\,\mathrm{gm}}$. This SAR reduction is better than the result reported in [5], which is 13% for $\mathrm{SAR}_{1\,\mathrm{gm}}$. This is achieved due to the use of different radiating powers and impedance factors.

Figures 3–6 show the SAR value in the distance between phone and head models, width of ferrite sheet between 20–40 mm, thickness of ferrite sheet between 2–3.5 mm and height between 40–80 mm respectively.

Table 1. Comparisons of peak SAR with ferrite sheet.

Tissue	SAR value (W/kg)
SAR value for [3]	2.17
SAR value for [4]	2.28
SAR value with ferrite sheet for 1 gm	1.043

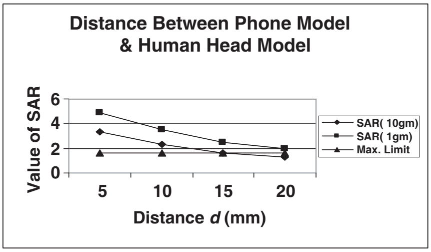

Figure 3. SAR value versus the distance between phone model and human head model.

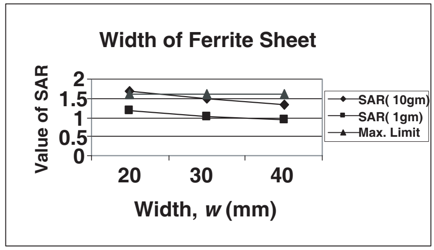

Figure 4. SAR value versus the width of the ferrite sheet.

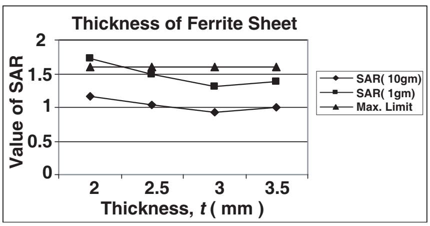

Figure 5. SAR value versus the thickness of ferrite sheet.

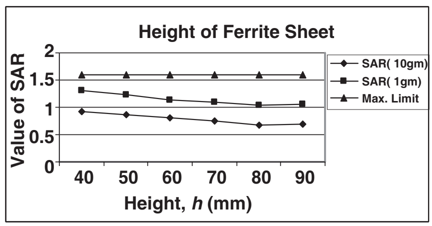

Figure 6. SAR value versus the height of the ferrite sheet.

The reduction effectiveness of the SAR depends on its width and height. In Figure 3, it is shown that if the distance between phone and human head models is varied then SAR value decreases. In Figure 4, it can be observed that the SAR value reduces with the increase of the width of ferrite sheet. As shown in Figure 5, the SAR value has decreased till the thickness of 3 mm, and it started to increase after 3 mm. The height is varied till 90 mm in Figure 6. From this figure it can be depicted that if the height of ferrite sheet increases SAR value also decreases up to height of 80 mm, and it started to increase after 80 mm. The results from Figures 5 and 6 imply that only suppressing the maximum current on the front side of conducting box contributes significantly to the reduction of spatial peak SAR. This is because the decreased quantity of the power absorbed in the head is considerably larger than that dissipated in the ferrite sheet.

3. SRRS DESIGN METHODOLOGY AND SAR REDUCTION

3.1. SRR Structure

From the FDTD analysis, the metamaterials can be used to reduce the peak $SAR_{1\,gm}$ in the head. In this section, the metamaterials operated at 900 and 1800 MHz bands of the cellular phone were designed. The metamaterials can be obtained by arranging SRRS periodically. The SRRS considered here consist of two square rings, each with gaps appearing on the opposite sides. The configuration has a geometry that is similar to the SRRS structures in [23]. As shown in Figure 7, the structure of a single SRR is defined by the following structure parameters: the square ring size l, the ring thickness c, the ring gap d, and the split gap g. The resonant frequency of SRRS can be shifted toward higher or lower frequency band by properly choosing these structure parameters.

3.2. SRR Design and Simulation

The metamaterials with negative permeability medium can be obtained by arranging split ring resonators (SRRS) periodically. The SRRS considered here consist of two concentric square rings, each with gaps appearing on the opposite sides. Figure 8 shows the details of SRRS. The resonant frequency ω is very sensitive to small changes in the structure parameters of SRR. The frequency response can be scaled to higher or lower frequency depends on properly choosing these geometry parameters [23].

$$\omega^2 = \frac{3lc_0^2}{\pi \ln \frac{2c}{d} r^3}$$

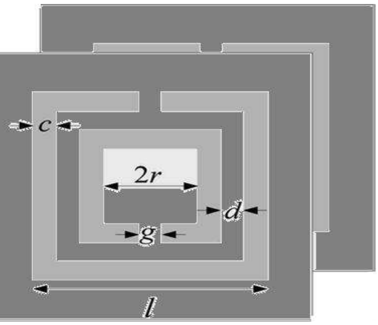

Figure 7. The structures of SRRS.

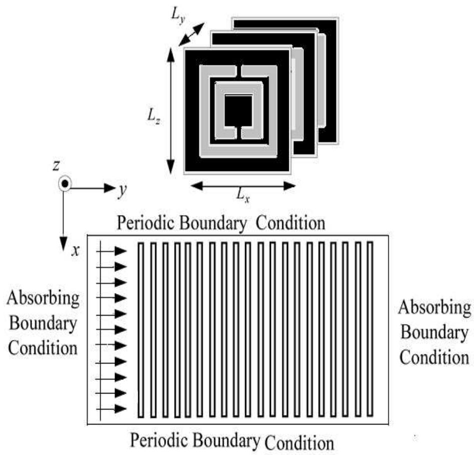

Figure 8. Top view of a plane wave incident on periodic (SRRS).

Numerical simulations could predict the transmission properties depending on various structure parameters of this system. Simulations of this complex structure are performed with FDTD method. To construct the SRRS for SAR reduction, the SRRS lie in the x-z plane are considered, as shown in Figure 8. The EM wave propagates along the y direction. The electric polarization is kept along the z-axis, and magnetic field polarization is kept along x axis. Periodic boundary conditions are used to reduce the computational domain, and absorbing boundary condition is used at the propagation regions. The total-field/scatter-field formulation was used to excite plane wave. The regions inside of the computational domain and outside of the SRRS were assumed to be vacuum [11].

The stop bands of SRRS are designed to be 900 MHz and 1800 MHz. The periodicity along x, y, z axes are $L_x = 63$ mm, $L_y = 1.5$ mm and $L_z = 63$ mm respectively. On the other hand, to obtain a stop band at 1800 MHz, the parameters of SRRS are chosen as $c = 1.8$ mm, $d = 0.6$ mm, $g = 0.6$ mm and $r = 12.9$ mm. The periodicity along x, y, z axes are $L_x = 50$ mm, $L_y = 1.5$ mm and $L_z = 50$ mm, respectively. The thickness and dielectric constant of the circuit boards for 900 MHz and 1800 MHz are 0.508 mm and 3.38 respectively. After properly choosing geometry parameters, the SRRS medium can display a stop band around 900 MHz and 1800 MHz respectively. From FDTD simulation, it is observed that the ring size is an important factor for operating frequency. The stop band can be shifted towards the lower frequency band by increasing the ring size.

3.3. SAR Calculation in the Head with Metamaterials

The metamaterials can be obtained by arranging SRRS periodically [24]. The metamaterials were placed between the antenna and human head. The distance between the antenna feeding point and the edge of metamaterials was 3 mm. The size of metamaterials in x-z-plane was 45 mm × 45 mm, and thickness was 6 mm. The SAR value and antenna performance with metamaterials were analyzed. CST Microwave Studio is utilized to simulate the metamaterials in human head model. Figure 9 shows the SAR distribution after perfectly design the metamaterial to simulate.

To study the effect of SAR reduction with the use of metamaterials, the radiated power from the helix antenna with $\mu = 1$ and $\varepsilon = -3$ mediums was fixed at 500 mW [11]. Numerical results are shown in Table 2. It is found that the use of metamaterials can reduce the peak $\text{SAR}_{1\,\text{gm}}$ by 42.12%. It can be observed from the results that the metamaterials can reduce peak SAR effectively, and the antenna performances can be less affected. The metamaterials resonate due to internal capacitance and inductance. This study has achieved 42.12%

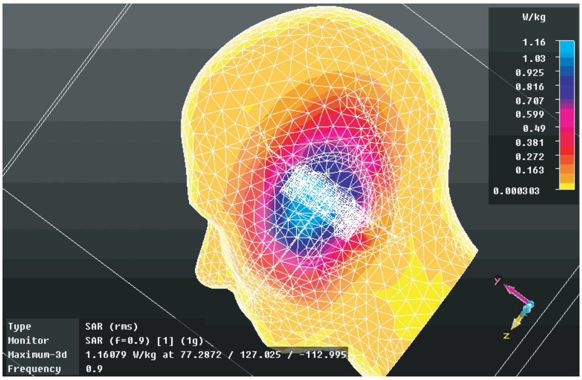

Figure 9. SAR distribution after reduction using metamaterial.

Table 2. Effects of comparisons with metamaterials on SAR reduction ($P_R = 0.5$ W for 900 MHz).

	900 MHz	
	Without material	$\mu = 1$, $\epsilon = -3$
$\text{SAR}_{1\,\text{gm}}$ value for [11]	2.43	1.89
$\text{SAR}_{1\,\text{gm}}$ value in the work	2.002	1.16079

of SAR reduction while the design reported in [11] achieved 22.63%. This is due to the consideration of different densities.

The use of metamaterials was also compared with other SAR reduction techniques. Ferrite material was commonly used in SAR reduction. Ferrite sheet was analyzed with the same size and position as metamaterials. The relative permittivity and permeability of ferrite sheet were analyzed with the same size and position as metamaterials. The relative permittivity and permeability of ferrite sheet were $\epsilon = 7.0 - j0.58$ and $\mu = 2.83 - j3.25$ respectively. [5, 11]. Comparisons of SAR reduction numerical results between materials and metamaterials are shown in Table 3. The SAR value has decreased about 1.043 for $\mathrm{SAR}_{1\,\mathrm{gm}}$ with materials and 1.16079 for $\mathrm{SAR}_{1\,\mathrm{gm}}$ metamaterials.

Table 3. Comparisons of SAR reduction with materials and metamaterials.

SAR(W/kg)	Material (Ferrite sheet)	Metamaterial
$\mathrm{SAR}_{1\,\mathrm{gm}}$	1.043	1.16079
$\mathrm{SAR}_{10\,\mathrm{gm}}$	0.676	0.737

4. CONCLUSION

The EM interaction between the antenna and the human head with materials and metamaterials has been discussed in this paper. With material SAR value is achieved about 0.676 for $\mathrm{SAR}_{10\,\mathrm{gm}}$, and with metamaterial the SAR value is achieved 0.737 for $\mathrm{SAR}_{10\,\mathrm{gm}}$. Based on the 3-D FDTD method with lossy-Drude model, it is found that the peak $\mathrm{SAR}_{1\,\mathrm{gm}}$ of the head can be reduced by placing the materials and metamaterials between the antenna and the human head. Metamaterials were designed from periodical arrangement of SRRS. Numerical results can provide useful information in designing communication equipments for safety compliance.

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