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A New Design of Split Ring Resonators for Electromagnetic (EM) absorption Reduction in Human Head

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Abstract: The reducing electromagnetic (EM) absorption reduction with a new type of triangular split ring resonators (TSSRs) based on triangular metamaterials (TMMs) attachment is investigated. The finite-difference time-domain method with lossy-Drude model is adopted in this investigation. The technique of EM absorption reduction is discussed and the effects of position, distance, and size of new design of metamaterials are investigated. Metamaterials have achieved a 63.40% reduction of the initial SAR value for the case of 10 gm SAR.

Keywords: antenna, human head model, lossy-Drude model, triangular metamaterials, specific absorption rate (SAR).

Nova oblika prekinjenih obročnih resonatorjev za zmanjševanje elektromagnetne absorpcije v človeški glavi

Izvleček: Raziskan je nov tip trikotno prekinjenih obročnih resonatorjev (TSSRs) na osnovih dodanih trikotnih meta kovinah (TMMs) za zmanševanje elektromagnetne (EM) absorpcije. Obdelana je metoda končnih diferenc v časovnem prostoru z izgubnim Drude modelom. Predstavljena in raziskana je tehnika zmanjševanja EM absorpcije in vpliv lokacije, razmika in velikosti novih oblik meta kovin. Metametali so dosegli 63.40% zmanjšanje začetne vrednosti SAR indeksa v primeru 10 gm SAR

Ključne besede: antena, model človeške glave, izgubni Drude model, trikotne meta kovine, specifična absorpcijska stopnja (SAR)

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1. Introduction

The basic parameter in the electromagnetic (EM) absorption is defined in terms of the specific absorption rate (SAR), or the absorbed power in unit mass of tissue [1]. The SAR is generally evaluated using either phantom measurement or computer simulation. The interaction of handset antennas with the human body is a great consideration in cellular communications. The user's body, especially the head and hand, influence the antenna voltage standing wave ratio (VSWR), gain, and radiation patterns. The interaction of the cellular handset with the human head has been investigated by many published papers considering; first, the effect of the human head on the handset antenna performance including the feed-point impedance, gain, and efficiency [2-7], and second, the impact of the antenna EM radiation on the user's head due to the absorbed power, which is measured by predicting the induced SAR in the head tissue [6-14]. In [6], a perfect electric conductor (PEC) reflector was placed 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 [8, 15], a study on the effects of attaching conductive materials to cellular phone for SAR reduction has been presented. It is shown that the position of the shielding material is an important factor for SAR reduction effectiveness.

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 and metamaterials to electromagnetic fields. The negative permittivity can be obtained by arranging the metallic thin wires periodically [11, 13]. On the other hand, an array of split ring resonators (SRRs) can exhibit negative effective permeability. In [7], the designed SRRs operated at 1.8 GHz were used to reduce the SAR value in a lossy material. The metamaterials are designed on circuit board so it may be easily integrated to the cellular phone. Simulation of wave propagation into metamaterials was proposed in [7, 15]. The authors utilized the FDTD method with lossy-Drude models for metamaterials simulation. This method is a helpful approach to study the wave propagation characteristics of metamaterials [11] and has been more developed with the perfectly matched layer (PML) and extended to three-dimension problem [7].

Since 2000, the rate of publications on electromagnetic-metamaterials has grown exponentially [11-16], indicative of the intense interest that artificial materials have generated. Specifically, the problems to be solved in SAR reduction need a correct representation of the cellular phone, anatomical representation of the head, alignment of the phone and the head, and suitable design of metamaterials.

2. Methodology

CST MWS, based on the finite integral time-domain technique (FITD), was used as the main simulation instrument. A non-uniform meshing scheme was adopted so that the major computation endeavor was dedicated to regions along the inhomogeneous boundaries for fast and perfect analysis. For two cut planes of the complete model indicating the area with denser meshing along the inhomogeneous boundaries. The minimum and maximum mesh sizes were 0.3 mm and 1.0 mm, respectively. A total of 2,122,164 mesh cells were generated for the complete model, and the simulation time was 1208 seconds (including mesh generation) for each run on an Intel Core TM 2 Duo E 8400 3.0 GHz CPU with 4 GB RAM system. At first materials are placed between the antenna and a human head, and then replaced by a metamaterial. In order to study the SAR reduction of an antenna operated at the GSM 900 band, the effective medium parameter of metamaterials is set to be negative at 900 MHz. Different positions, sizes, and negative medium parameters of metamaterials for SAR reduction effectiveness are also analyzed. The SAM head model was considered for this research where it consists about 2,097,152 cubical cells with a resolution of 1 mm. Fig. 1 shows a portable telephone model at 900 MHz for the present. It was considered to be a quarter wavelength PIFA antenna mounted on a rectangular conducting box. The conducting box was 10 cm tall, 4 cm wide, and 3 cm thick. The PIFA antenna was located at the top surface of the conducting box.

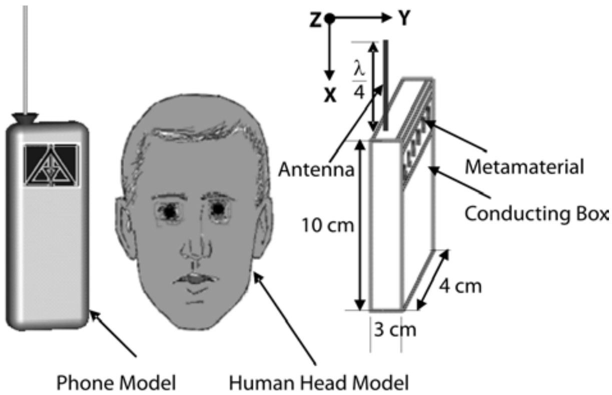


Figure 1: The head and antenna model for SAR calculation.

3. TSRRs Construction and Design

We establish that the TMMs can be used to reduce the peak SAR 1 gm and SAR 10 gm in the head from the FDTD analysis. In this section, the TMMs are operated at the 900 and 1800 MHz bands of the cellular phone were considered. The TMMs can be attained by arranging TSRRs periodically. The TSRRs structure consists of two concentric triangular ring of conductive material. There is a gap on each triangular ring, and each triangular ring is situated opposite to the gap on the other ring. The schematics of the TSRRs structure that we used in this study as shown in Fig. 2.

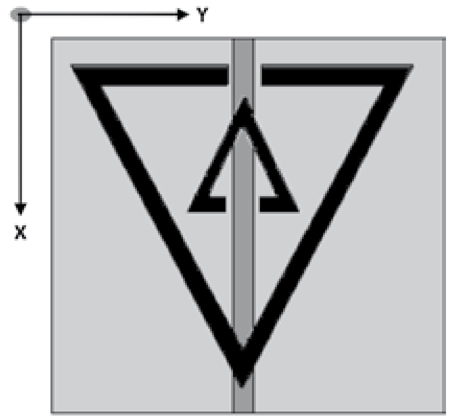


Figure 2: The structure of the TSRRs.

To construct the TMMs for SAR reduction, we proposed one model of resonators namely the TSRRs as shown in Fig. 2. We design the resonators for operation at the 900 MHz bands. The TSRRs contains two triangular rings, each with gaps appearing on the opposite sides. The SRRs was introduced by Pendry et al. in 1999 [10] and subsequently used by Smith et al. for synthesis of the first left-handed artificial medium [12]. We design the metamaterials from periodically arrangement of SRRs to reduce the SAR value. By properly designing structure parameters of TSRRs, the effective medium parameter can be negative around 900 and 1800 MHz band. In Fig. 2, the structures of resonators are defined by the following structure parameters: the triangular ring thickness c, the triangular ring gap d, the triangular ring size l, the split gap g, and c_0 is the speed of light in free space. The resonant frequency ω is very sensitive to small changes in the structure parameters of TSRRs.The frequency response can be scaled to higher or lower frequency by properly choosing these geometry parameters by utilizing the following equation [15].

$$\omega^2 = \frac{3lc_0^2}{\pi \ln \frac{2c}{d} r^3} \tag{1}$$

The TSRRs is resonating at approximately half the guided-wavelength of the resonant frequency. There are two resonances from the split rings. We have given the formula for the resonance of the outer split ring, which has a lower resonance frequency.

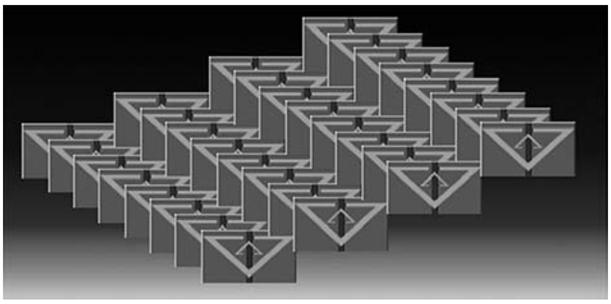


Figure 3: The structure of the TSRRs array used in this simulation.

Figure 3 shows the arrays of TSRRs based on TMMs design used in this simulation. In the new design of metamaterials we have considered 28 elements in the propagation direction which will reduce the thickness and metamaterial size. In our new design research found that metamaterial design; specifically ring size, ring thickness is an important factor for SAR reduction.

4. Results & Discussion

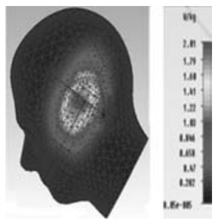
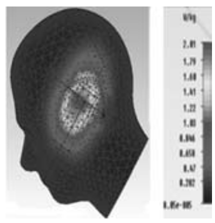
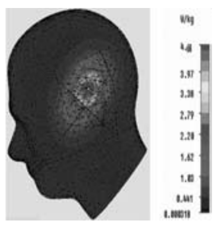
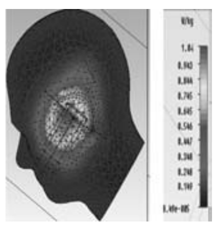
The designed of triangular split ring resonators (TSRRs) were placed between the antenna and a human head thus reducing the SAR value. In order to study SAR reduction of an antenna operated at the GSM 900 band, different positions, sizes, and metamaterials for SAR reduction effectiveness are also analyzed by using the FDTD method in conjunction with a detailed human head model. 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 the metamaterials. Besides that, the output power of the mobile phone model needs to be set before SAR is simulated. In this paper, the output power of the cellular phone is 600 mW at the operating frequency of 900 MHz. In the real case, the output power of the mobile phone will not exceed 250 mW for normal use, while the maximum output power can reach to 1 W or 2 W when the base station is far away from the mobile station (cellular phone). The calculated peak SAR 1 gm value is 2.002 W/kg, and SAR 10 gm value is 1.293 W/kg when the phone model is placed 20 mm away from the human head model without a metamaterial. This SAR reduction is better than without metamaterials attachment, the result reported in [6], and [8], which is 2.28 W/kg and 2.17 W/kg, for SAR 1 gm. This is because the mobile antenna position, and antenna sizes is not properly situated, and antenna is different also. This SAR value is better compared with the result reported in [7], which is 2.43 W/kg for SAR 1 gm. This is achieved using different radiating powers and different antenna.

The use of metamaterials was also compared with other SAR reduction techniques. A PEC reflector and a ferrite material are commonly used in SAR reduction. The PEC reflector and ferrite sheet were analyzed. The relative permittivity and permeability of the ferrite sheet were ε =7.0-j0.58 and μ =2.83-j3.25, respectively. A PEC placed between the human head and the antenna is studied. It can be found that the peak SAR 1 gm is increased with the use of a PEC reflector. This is because the EM wave can be induced in the neighbour of a PEC reflector due to scattering. When the size of PEC sheet is small compared to the human head, the head will absorb more EM energy. Similar results of peak SAR increase with PEC placement were also reported in [7].

The use of a ferrite sheet can reduce the peak SAR 1 gm effectively. However, the degradation on radiated power from the antenna is also significant. In addition, compared to the use of a ferrite sheet, the metamaterials can be designed on the circuit board so they may be easily integrated to the cellular phone.

To study the effect of SAR reduction with the use of new type of metamaterials, the radiated power from the PIFA antenna with $\mu = 1$ and $\varepsilon = -3$ mediums was fixed at 600 mW. Numerical results are shown in Table 1. It is found that calculated SAR value at 900 MHz, without the metamaterial, is 2.002 W/kg for SAR 1 gm and with the metamaterial, the reduction of the SAR 1 gm value is 1.0963 W/kg. The reduction is 45.44 % where as the design reported in [7] achieved 22.63%. This is achieved due to the consideration of different density, different antenna, and different size of metamaterial and different type of conductivity. The SAR reduction is better than that our previous research (where we achieved about 42.12 %) [15], due to the use of new metamaterials. Furthermore, the size of the mobile phone was considered 61 mm but in our previous paper [15] it was considered 63 mm. From simulation results, the metamaterials can reduce peak SAR effectively and the antenna performance can be less affected. The metamaterials are resonant due to internal capacitance and inductance. The mediums will display a stop band with a single negative medium parameter.

Table 1: Comparisons of SAR reduction techniques with different materials

	Z_R (Ω)	P_R (mW)	Peak head SAR (W/Kg)	
			1 gm	10 gm
Without material	63.39 + j94.53	600		
			2.002	1.673
$\mu = 1$, $\varepsilon = -3$ (Metamaterial)	51.04 + j98.94	512.7		
			1.0724	0.8215
PEC reflector	66.83 + j32.23	509.3		
			4.6803	3.278
Ferrite Sheet	51.43 + j99.68	519.3		
			1.043	0.676

5. Conclusion

The EM absorption between an antenna and the human head with new type of metamaterials has been discussed in this paper. Utilizing metamaterial in the phone model a SAR value is achieved of about 0.692 W/kg for SAR 10 gm and 1.0923 W/kg for SAR 1 gm is achieved. Numerical results can provide useful information in designing communication equipment for safety compliance.

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