

INFLUENCE OF SAR REDUCTION IN MUSCLE CUBE WITH METAMATERIAL ATTACHMENT

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Key words: SAR, SAR reduction, muscle cube, metamaterial attachment, mobile communication equipment

Abstract: The purpose of this paper is to calculate the specific absorption rate (SAR) reduction in muscle cube with metamaterial attachment. The finite-difference time-domain (FDTD) method has been used to evaluate the SAR in a realistic anatomically based model of the muscle cube. We design the single negative metamaterials from periodic arrangement of split ring resonators (SRRS). By properly designing structural parameter of SRRS, the effective medium parameter can be made negative at 900 MHz and 1800 MHz band in this paper. Numerical results of SAR values in muscle cube with presence of resonators exhibit SAR reduction. These results can provide useful information in designing safety mobile communication equipment compliance.

Zmanjšanje SAR v modelu mišične kocke z dodatkom metamateriala

Ključne besede: SAR, zmanjšanje SAR, mišična kocka, dodatek metamateriala, mobilne komunikacijske naprave

Izleček: Namen članka je izračunati zmanjšanje specifične stopnje absorpcije (SAR) v mišični kocki z dodatkom metamateriala. Za ocenjevanje SAR v realnem anatomskem modelu mišične kocke je bila uporabljena FDTD (finite-difference time-domain) metoda. Model metamaterialov smo izdelali s pomočjo periodične strukture resonatorjev tipa SRRS (SRRS – split-ring resonator). Z ustrezno izbiro strukturnih parametrov SRRS lahko dosežemo negativno prepustnost pri frekvencah 900 MHz in 1800 MHz.

Numerični rezultati SAR vrednosti v mišični kocki ob prisotnosti resonatorjev SRRS kažejo na zmanjšanje SAR. Rezultati so tako uporaben vir informacij pri načrtovanju varnih mobilnih komunikacijskih naprav.

1. Introduction

The portable terminal devices are widely used in the human life. As usages of the mobile devices are increased, the study about the health risk from the hazard electromagnetic fields is widely in progress. The specific absorption rate (SAR) is defined parameter for evaluating power absorption in the human head. Radio frequency (RF) safety guidelines have been issued to prevent excessive electromagnetic-field exposure in terms of the SAR [1]. The exposure of the human head to the near field of a cellular phone has been evaluated by measuring the SAR in a human-head phantom, or by calculating it using a human-head numerical model. Therefore, it is important issue of the portable devices that reduction of SAR value. Previously, a ferrite sheet between the antenna and a head, a position study of the antenna feeding point; a use of the conductive material (such as aluminum), and electromagnetic band gap (EBG) structures to design high performance devices, were proposed to reduction of the SAR value [2-4].

Recently, there are many interests on metamaterial with split ring resonator structure were proposed to reduction of the SAR value [5]. The negative permittivity can be obtained by arranging the metallic thin wires periodically [6]. On the other hand, an array of split ring resonators (SRRS)

can exhibit negative effective permeability. The designed SRRS operated at 1.8 GHz and were used to reduce the SAR value in a lossy material. 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 [5-7]. 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 [8-9] and has been more developed with the perfectly matched layer (PML) and extended to three-dimension problem [7].

At first, the SRRS are used to reduce the EM interface between a helix antenna and a muscle cube. With properly choosing geometry parameters of SRRS, the permeability can be negative at 900 MHz and 1.8 GHz, respectively. The SAR circulation in a muscle tissue with the presence of SRRS is studied. To explore the influence of SRRS to the antenna, the radiated power and radiation impedance of the antenna are also analyzed. Numerical results are established to confirm the effect of SAR reduction.

This paper is structured as follows. Section II describes the SRRS design and simulation between handset antenna and

the SAM phantom head, and SAR calculation in a muscle cube will be described in Section III, Section IV concludes the paper.

2. SRRS Design and Simulation

To construct the metamaterial for SAR reduction, we proposed one model of resonators namely the SRRS as shown in Fig. 1. We design the resonators for operation at the 900 MHz bands. The SRRS contains two square rings, each with gaps appearing on the opposite sides /5/. The SRRS was introduced by Pendry et al. in 1999 /8/ and subsequently used by Smith et al. for synthesis of the first left-handed artificial medium /9/. A lot of effort worldwide has been spent studying single negative metamaterials (SNMs), double negative metamaterials (DNMs), their properties /6/, applications in antennas /7/, and other microwave devices. In Fig. 1, the structures of resonators are defined by the following structure parameters: the ring thickness c , the ring gap d , the square ring size l , the split gap g , and c_0 is the speed of light in free space. The resonant frequency f is very sensitive to small changes in the structure dimensions of the SRRS. The frequency response can be scaled to higher or lower frequency by properly choosing these geometry parameters. After an extensive simulation study, we have found out a closed-form formula for the resonant frequencies of the SRRS:

$$f_{SRRS} = k_1 \frac{c_0}{2[4(2r_{ext} - c) - g]\epsilon_r^{1/2}} \quad (1)$$

The SRRS 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.

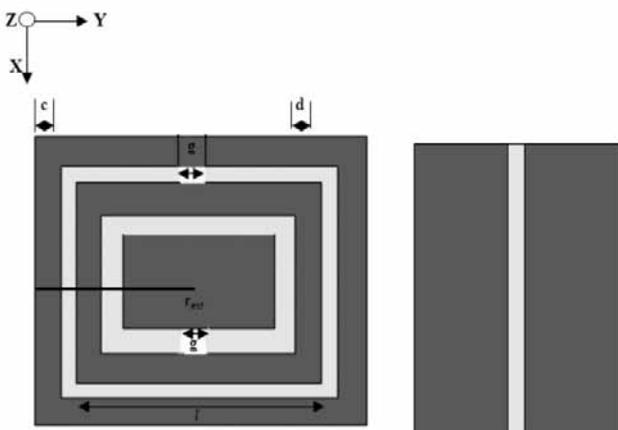


Fig. 1. The structure of SRRS (a) front-side and (b) back-side views

Numerical simulations could predict the transmission properties depend 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 xz plane are considered. 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 an absorbing boundary condition is used at the propagation regions. The total-field/scatter-field formulation is used to excite the plane wave. The regions inside of the computational domain and outside of the SRRS were assumed to be vacuum.

From this study, it is found that both of the two incident polarizations can produce a stop band. As shown in /4-6/, the stop band corresponds to a region where either the permittivity or permeability is negative. When the magnetic field is polarized along the split ring axes, it will produce a magnetic field that may either oppose or enhance the incident field. A large capacitance in the region between the rings will be generated and the electric field will be powerfully concentrated. There is strong field coupling between the SRRS and the permeability of the medium will be negative at the stop band. Because the magnetic field is parallel to the plane of SRRS, we imagine the magnetic effects are small, and that permeability is small, positive, and slowly varying. In this condition, these structures can be viewed as arranging the metallic wires periodically.

The stop bands of the SRRS are designed to be at 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 the SRRS are chosen as $c = 1.8$ mm, $d = 0.6$ mm, $g = 0.6$ mm, and $r = 12.9$ mm. The periodicity along the x , y , z axes are $L_x = 50$ mm, $L_y = 1.5$ mm, and $L_z = 50$ mm, respectively. Both the thickness and dielectric constant of the circuit boards for 900 MHz and 1800 MHz are 0.508 mm and 3.38 mm respectively. After properly choosing geometry parameters, the SRRS medium can display a stop band around 900 MHz and 1800 MHz. SRRS producing a good stop band and size are large. Therefore, SRRS are suitable for mobile phones as per size and recital point of view.

We have tried to use a high impedance surface configuration to reduce the peak SAR. However, we found that when these structures operate at 900 MHz, the sizes of these structures are too large for cellular phone application. A negative permittivity medium can also be constructed by arranging the metallic thin wires periodically /7/. However, we found that when the thin wires operate at 900 MHz, the size is also too large for practical application. Because the SRRS structures are significant due to internal capacitance and inductance, they are on a scale less than the wavelength of radiation. Fig.2 shows the modeled transmission coefficient. It can be clearly seen from this figure that after properly choosing geometry parameters, the SRRS medium can display a stop band around 900 MHz and 1800 GHz respectively.

3. SAR calculation in a muscle cube

To verify our FDTD simulation, the structure parameters of SRRS were chosen as same as /5/. Since a 3-D model of the whole head with the presence of SRRS structure requires a great amount of memory, a simplified muscle cube is used to validate the effect of SAR reduction. Fig. 3 shows the muscle cube used in SAR simulation. It is formed by muscle tissue with $\epsilon_r = 51.8$, $\sigma = 1.11$, and $\rho = 1040$ for 900 MHz and $\epsilon_r = 49.4$, $\sigma = 1.53$, and $\rho = 1040$ for 1800 MHz. A $\lambda/2$ helix antenna is placed near the muscle tissue. The distance between the antenna and the muscle cube is 20 mm. The radiated power from the antenna is assumed to be 600 mW for 900 MHz and 125 mW for 1800 MHz, respectively. The designed SRRS are placed between the antenna and the muscle cube. The medium with parameters $N_x=1$, $N_y=10$, and $N_z=1$ unit elements along each direction are used. The sizes of the muscle cube are chosen to be the length of the $\lambda/2$ helix antenna.

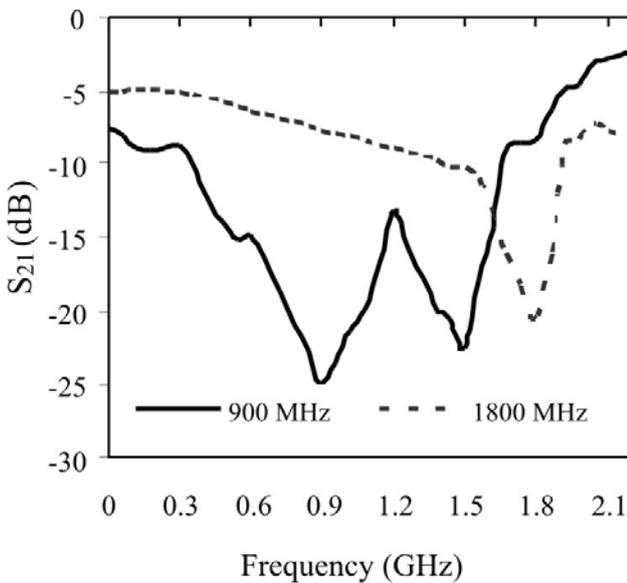


Fig.2. Modeled transmission spectra of the designed SRRS

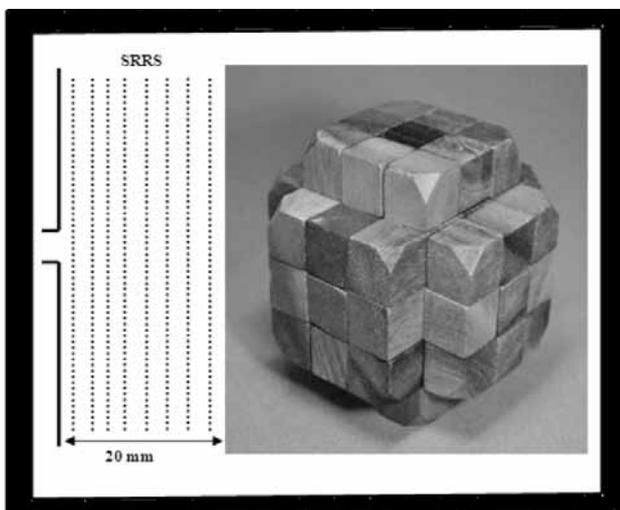


Fig. 3. Structure used in SAR calculation

To investigate the SAR distribution and antenna performance with SRRS, the power radiated from the antenna, the radiation impedance of the antenna, and the peak 1 gm averaged SAR values (SAR 1 gm) are analyzed. The free space radiation impedance of the antenna, in the absence of the SRRS and the muscle cube, is Z_{R0} . As in /7/, to evaluate the power radiated from the antenna, the source impedance (Z_s) has been assumed equal to the complex conjugate of the free space radiation impedance ($Z_s = Z_{R0}^*$). The source voltage (V_s) is chosen to obtain a radiated power

P_R in free space ($V_s = \sqrt{P_R \times 8 \times R_{R0}}$). When analyzing the influence of the metamaterials to the radiated power from the antenna, the source impedance and the source voltage are considered fixed at the Z_s and V_s values. The power radiated from the antenna is evaluated by computing the radiation impedance in this situation ($Z_R = R_R + jX_R$) and using the following equations:

$$P_R = \frac{1}{2} V_s^2 \frac{R_R}{|Z_R + Z_s|^2} \tag{2}$$

Table 1: Effects of srrs on the antenna performance

	900 MHz		1800 MHz	
	Without SRRS	With SRRS	Without SRRS	With SRRS
Z_R	49.48+ j48.81	37.32+ j42.94	61.81+ j85.86	81.63 + j93.94
P_R	600 mW	523.4 mW	125 mW	116.7 mW

The effects of SRRS on the performance of the antenna are studied. The radiation impedance and radiated power are given in Table I and compared with the results without SRRS placed between the antenna and the muscle cube. The free space radiation impedance is $49.48 + j48.81 \Omega$ at 900 MHz. The source impedance is set to be $49.48 + j48.81 \Omega$ and the amplitude of source voltage 21.25 V has been assumed to obtain a radiated power 600 mW in free space. The radiation impedance Z_R changes to $37.32 + j42.94 \Omega$ with the presence of SRRS. From eqn. (2), the radiated power from the antenna with SRRS changes to 523.4 mW. The peak SAR 1 gm becomes 3.62 W/kg, a reduction of 44.73% with respect to the condition without SRRS. The antenna operated at 1800 MHz is considered. The free space radiation impedance is $61.81 + j85.86 \Omega$. The source impedance is set to be $61.81 + j85.86 \Omega$ and the amplitude of source voltage 8.85 V has been assumed to obtain a radiated power 125 mW in free space. The radiation impedance Z_R changes to $81.63 + j93.94 \Omega$ with the presence of SRRS. As a result, from eqn. (2) the radiated power with SRRS changes to 116.7 mW and the peak SAR 1 gm is equal to 0.45, a reduction of 48.27% with respect to the condition without SRRS. The radiated power is less affected while the peak SAR 1 gm is reduced more significantly. As a consequence, the designed SRRS can be used to reduce the EM interaction between the antenna and the muscle cube.

The SAR distribution is compared with the value reported in /5/ for validation, as shown in Table II. The calculated peak

SAR 1 gm value is 6.73 W/kg for 900 MHz and 0.87 W/kg for 1800 MHz, when the portable telephones is placed 20 mm away from the muscle cube without a metamaterial. This SAR value is better compared with the result reported in /8/, which is 8.85 W/kg at 900 MHz and 0.97 W/kg at 1800 MHz for SAR 1 gm. The SRRS is utilized in between the antenna and muscle cube, and it is found that the simulated value of SAR 1 gm 3.62 W/kg at 900 MHz and 0.45 W/kg at 1800 MHz for SAR 1 gm respectively. The reduction about of 44.73% for 900 MHz was observed in this study when a SRRS is attached between the antenna and muscle cube for SAR 1 gm and also 48.27% for 1800 MHz respectively This SAR reduction is better than the result reported in /5/, which is 36.8% at 900 MHz and 44.3 % at 1.8 GHz for SAR 1 gm. This is achieved due to the consideration of different thickness, different antenna, different size of metamaterial, different impedance factors, different positions and it is because the electromagnetic source is being moved away from the head.

Table 2: Comparisons of peak sar with metamaterial in a muscle cube

Tissue Type	900 MHz		1800 MHz	
	Without Metamaterial /W/kg/	With Metamaterial /W/kg/	Without Metamaterial /W/kg/	With Metamaterial /W/kg/
SAR value for /5/	8.85	5.59	0.97	0.54
SAR value with metamaterial for 1 gm	6.73	3.62	0.87	0.45

The influence of the distance, area and the thickness of the metamaterials on the SAR reduction effect are shown in Figs. 4, 5, and 6.

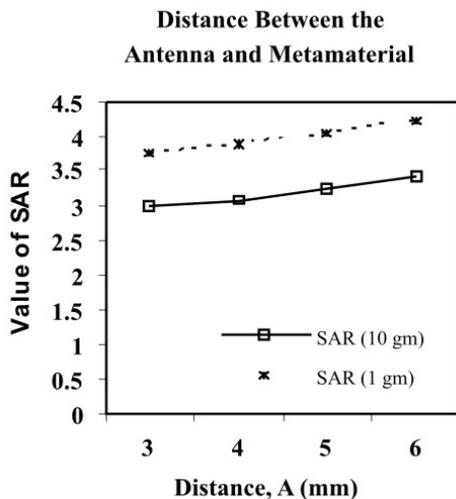


Fig. 4 SAR value compared with the distance between antenna and the metamaterial

In Fig. 4, it is shown that there is a great influence of the distance between the antenna and metamaterial on SAR reduction. If the distance between the antenna and metamaterial is increased from 3 mm to 6 mm, then the SAR value also increases from 2.9811 to 3.4112 W/kg for SAR 10 gm and 3.7505 to 4.2319 W/kg for SAR 1 gm respectively. This is because the dielectric constant, conductivity, density and magnetic tangent losses conductivity are also

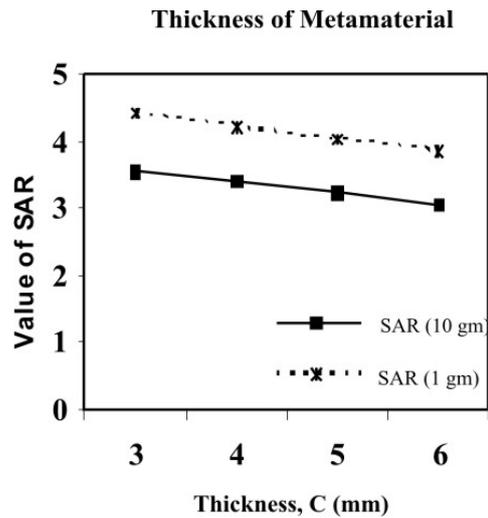


Fig.5 SAR value compared with the thickness of the metamaterial

varied. In Fig. 5, it can be observed that the SAR value increases with the decrease of the thickness of metamaterial. The SAR value reduces quickly when metamaterial size is large 48 mm × 48 mm to 56 mm × 56 mm then the SAR value also reduces from 3.2308 to 2.9211 W/kg for the cases of SAR 10 gm and 4.1831 to 3.9201 W/kg for SAR 1 gm as can be seen from Fig. 6.

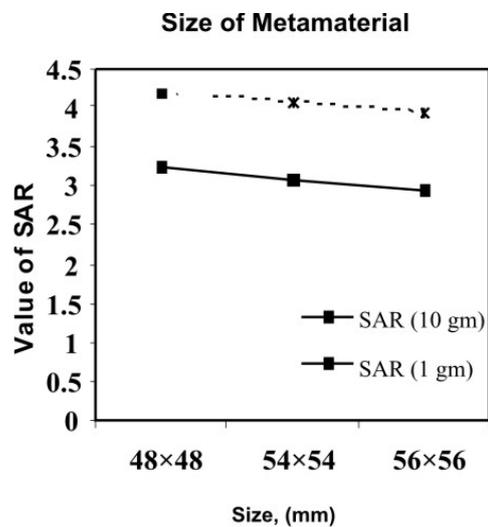


Fig.6 SAR value compared with the size of the metamaterial

varied. In Fig. 5, it can be observed that the SAR value increases with the decrease of the thickness of metamaterial. The SAR value reduces quickly when metamaterial size is large 48 mm × 48 mm to 56 mm × 56 mm then the SAR value also reduces from 3.2308 to 2.9211 W/kg for the cases of SAR 10 gm and 4.1831 to 3.9201 W/kg for SAR 1 gm as can be seen from Fig. 6.

4. Conclusion

The metamaterials has been designed to reduce SAR value in muscle cube in this paper. With properly choosing ge-

ometry parameters of SRRS, the stop band can be shifted around GSM 900 MHz and 1.8 GHz of the cellular phone. The SAR distribution in a simplified muscle tissue with the presence of SRRS is studied and a significant reduction can be obtained. The SAR value with metamaterial attachment for 900 MHz has been achieved of 44.73% with respect to the condition without SRRS and also SAR value has been for 1800 MHz achieved of 48.27% respectively. Numerical results can provide useful information in designing communication equipments for safety compliance.

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