SAR REDUCTION IN HUMAN HEAD FROM MOBILE PHONE RADIATION USING SINGLE NEGATIVE META-MATERIALS

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Abstract—In this paper, we use single negative metamaterials to reduce the electromagnetic interaction between the mobile phone and human head. The specific absorption rate (SAR) in the head can be reduced by placing the metamaterials between the antenna and the head. We design the single negative metamaterials from periodic arrangement of split ring resonators (SRRs), spiral resonators (SRs) and open split ring resonators (OSRRs). By properly designing structural parameters of SRRs, the effective medium parameter can be traded negative around 900 MHz and 1800 MHz bands. The design procedure and principle operation of resonators are explained. The performance and size comparison of resonators will be described. Numerical results of the SAR values in the human head with the presence of resonators exhibit SAR reduction. These results can provide useful information in designing safety mobile communication equipments compliant.

1. INTRODUCTION

The use of mobile phone has been increasing rapidly. As the technology is moving from wired to wireless, the electromagnetic pollution is increasing. When you talk on your cell phone, your voice is transmitted from the antenna as radio frequency radiation (RFR) between 800 MHz and 1,990 MHz; this frequency falls in the range of microwave radiation. Cell phones are designed to transmit radio waves in all directions because base stations can be located in any direction with respect to phone users. This means that some portions of the radio waves they
produce are directed towards your body. The rate at which radiation is absorbed by the human body is measured by the Specific Absorption Rate (SAR). As per the international safety guidelines [1, 2] the SAR must be below the limits. Some results have implied that the peak 1g averaged SAR value may exceed the safety limits when a mobile telephone is placed extremely close to the head. Therefore, many researchers are working on reducing the SAR distribution in human head.

In this paper, the single negative metamaterials are used for reducing the SAR. Metamaterials have great unique physical properties and novel application [3, 4]. 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. A negative permeability can be obtained by arranging an array of resonators.

2. HEAD MODEL AND SAR CALCULATION

In this model design, a Planar Inverted F-Antenna (PIFA) and human head model are used. The equivalent diagram is as shown in Fig. 1. The antenna was arranged parallel to the head axis and the distance between the antenna and the head is $D = 25\text{mm}$. The planar inverted F antenna is popular for portable wireless devices because of its low profile, small size, and build-in structure [5]. The other

![Figure 1. The antenna and human head model for SAR calculation.](image-url)
major advantages are easy fabrication, low manufacturing cost, and simple structure [6]. PIFA is a practical antenna, generally used in GSM mobile phones. The position of the handset mounting PIFA is tilted by 30°. The face of antenna is in the opposite direction from the human head. The radiated power from the antenna was assumed to be 600 mW at 900 MHz.

2.1. SAR Calculation

SAR is defined as

$$\text{SAR} = \frac{1}{2\rho}E^2$$

The SAR value was calculated for an antenna output power equal to 600 mW. To evaluate mobile telecommunication equipment, standard methods for measurement of the SAR are presently under discussion by international standard organizations [7, 8]. In these standards, SAR is determined by measuring the electric field distribution in an artificial head (head phantom) made of a head shaped shell and filled with tissue equivalent dielectric liquid. The proposed human head model for SAR calculation is as shown in Fig. 2. It consists of three layers. The outer most layer in the human head is skin with thickness of 0.5 cm, The second layer represents the human bone with thickness of 0.5 cm and the inner layer is the human brain with radius of 7.25 cm. The electrical properties of skin, bone and brain are shown in Table 1. No distinction was made between white and grey brain tissues, even though they have different dielectric properties. It should be noted that the averaged values between white and grey brain tissues were used as the electrical properties of brain [9]. The calculated peak SAR\(_{1g}\) in the human head is 8.7906 W/kg. By increasing the distance (\(D\)) between the antenna and human head the SAR value is decreased. By decreasing the value of \(D\), The SAR value is increased. For the different values of \(D\) the peak SAR is as shown in Table 2.

<table>
<thead>
<tr>
<th>TISSUE</th>
<th>(\varepsilon_r)</th>
<th>(\sigma) (S/m)</th>
<th>(\rho) (kg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKIN</td>
<td>39.5</td>
<td>0.69</td>
<td>1010</td>
</tr>
<tr>
<td>BONE</td>
<td>17.4</td>
<td>0.19</td>
<td>1810</td>
</tr>
<tr>
<td>BRAIN</td>
<td>45.8</td>
<td>0.76</td>
<td>1025</td>
</tr>
</tbody>
</table>

Table 1. Electrical properties of different tissues at 900 MHz.
Table 2. Calculated SAR value in the human head for different values of $D$.

<table>
<thead>
<tr>
<th>Distance between antenna and human head ($D$)</th>
<th>$D = 10$ mm</th>
<th>$D = 15$ mm</th>
<th>$D = 20$ mm</th>
<th>$D = 25$ mm</th>
<th>$D = 30$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR value (W/kg)</td>
<td>9.9629</td>
<td>9.3130</td>
<td>9.0162</td>
<td>8.7906</td>
<td>8.1281</td>
</tr>
</tbody>
</table>

Figure 2. Human head model for SAR calculation.

2.2. Reduction of SAR Using Single Negative Metamaterials

The SAR in the head can be reduced by placing the metamaterials between the antenna and the head. The metamaterials is on a scale less than the operating wavelength. The structures are resonant due to internal capacitance and inductance. The stop band can be designed at operation bands of cellular phone radiation. The metamaterials are designed on a printed circuit board so it may be easily integrated to the cellular phone. By arranging sub-wavelength resonators periodically we get the metamaterials. To construct the metamaterials for SAR reduction, we proposed three models of resonators namely SRR, SR and OSRR as shown in Fig. 3. We design the resonators for operation at 900 MHz bands. The SRRs contain two square rings, each with gaps appearing on the opposite sides [4] and SRs contain three square rings. The OSRR is a modification of the SRR. SRR introduced by Pendry
et al. in 1999 [10] and subsequently used by Smith et al. for synthesis of the first left-handed artificial medium [11]. A lot of effort worldwide have been spent studying the Single Negative Metamaterials (SNMs), Double Negative Metamaterials (DNMs), its properties [12–16], applications in antennas [17–19] and other microwave devices [20–22]. As shown in Fig. 3, the structures of resonators are defined by the following structure parameters: the ring thickness $c$, the ring gap $d$, 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 SRR. 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 the close-form formula for resonant frequencies of SRR, SR and OSRR.

$$f_{\text{SRR}} = k_1 \frac{c_0}{2(4(2r_{\text{ext}} - c) - g)\epsilon_r^{1/2}}$$  \hspace{1cm} (2)

SRR is resonating approximately half the guided-wavelength of the resonant frequency. The resonating current paths are depicted in Fig. 3. 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. Constant $k_1$ can be chosen as 1.1.

$$f_{\text{SR}} = k_2 \frac{c_0}{2(12r_{\text{ext}} - 6c - g - 6d + (g^2 + d^2)^{1/2})\epsilon_r^{1/2}}$$  \hspace{1cm} (3)

SR is resonating approximately guided-wavelength of the resonant frequency. $k_2$ is round out to be approximately 1.25.

$$f_{\text{OSRR}} = k_3 \frac{c_0}{2(2\Pi(r_{\text{ext}} - c/2) - g) + l)\epsilon_r^{1/2}}$$  \hspace{1cm} (4)

Figure 3. The structures of SRR, SR and OSRR.
OSRR is resonating approximately half the guided-wavelength of the resonant frequency. Constant $k_3$ is approximately 1.1. The resonance we have calculated is for the outer ring which has a lower resonance frequency.

To construct the resonators for SAR reduction, let us assume that the resonators lie in the $xy$ plane are considered. The EM wave propagates along the $z$ direction. The electric field polarization is kept along the $y$ axis, and magnetic field polarization is kept along $x$ axis. The stop bands of resonators are designed to be 900 MHz. To obtain a stop band at 900 MHz, the parameters of resonators are chosen as $c = 0.5$ mm, $d = 0.5$ mm, $g = 0.5$ mm, and the external radius of SRRs, SRs, OSRRs as 9.1 mm, 4.34 mm, 5.8 mm respectively.

After properly choosing geometry parameters, the resonators medium can display a stop band around 900 MHz and the corresponding curve as shown in Fig. 4. For the mobile designing, the smallest size of resonators is suitable. The size of SRs is very small but performance is not good. SRRs producing a good stop band and size are very large. OSRRs producing the good stop band almost equal to the SRRs and size are almost half of the SRRs. Therefore, OSRRs are suitable for mobile phones as per size and performance point of view.

### 2.3. Reduced SAR

The designed SRRs were placed between the antenna and the head. Fig. 5 shows the head used in SAR simulation. The calculated SAR value at 900 MHz, with no SRRs is 8.0741 W/kg and with 10 SRRs the SAR value is 5.2058 W/kg. The reduction is 35.52%. The SAR and antenna performance with resonators were studied and the results are

![Figure 4. Performance of single SRR, SR and OSRR.](image-url)
given in Table 3. The reduced SAR value with 3 SRRs, 3 SRs and 3 OSRRs are 7.1032 W/kg, 7.5321 W/kg and 6.0388 respectively. The reduction of SAR with 3 SRRs, 3 SRs and 3 OSRRs are 19.19%, 14.31% and 31.30% respectively. The reduced SAR value with 10 SRRs, 10 SRs and 10 OSRRs are 5.2058 W/kg, 7.0216 W/kg and 3.7099 respectively. The reduction of SAR with 10 SRRs, 10 SRs and 10 OSRRs are 35.52%, 20.12% and 57.89% respectively.

**Figure 5.** The antenna, metamaterials and head model for SAR reduction.

### 3. COMPARISON OF RESONATORS

For the design of negative metamaterials we proposed 3 types of resonators SRRs, SRs and OSRRs. By properly designing the structure parameters of resonators we achieved stop band at 900 MHz. The Fig. 4 shows the response of single resonator. From the Fig. 4, OSRR producing a good stop band. Even though SRR having a good stop band, it is not suitable for mobile phones because the size is very large. The SR size is very small but it does not produce good stop band. The reduced SAR with 3 and 10 resonators are shown in Table 3. From the Table 3 with 10 SRRs we are getting 35.52% only, with 10 OSRRs we are getting 57.89% and size is very small. In [23], a ferrite sheet was proposed to use as a protection attachment between the antenna and a head. It was found that a ferrite sheet can result in SAR reduction and the radiation pattern of the antenna can be less affected. In [24],
Table 3. Comparison of SAR reduction at 900 MHz.

<table>
<thead>
<tr>
<th>Resonator type</th>
<th>$r_{ext}$ (mm)</th>
<th>Without resonators (W/Kg)</th>
<th>With 3 resonators (W/Kg)</th>
<th>Reduction (%)</th>
<th>With 10 resonators (W/Kg)</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRR</td>
<td>9.1</td>
<td>8.7906</td>
<td>7.1032</td>
<td>19.19%</td>
<td>5.2058</td>
<td>35.52%</td>
</tr>
<tr>
<td>SR</td>
<td>4.34</td>
<td>8.7906</td>
<td>7.5321</td>
<td>14.31%</td>
<td>7.0216</td>
<td>20.12%</td>
</tr>
<tr>
<td>OSSR</td>
<td>5.8</td>
<td>8.7906</td>
<td>6.0388</td>
<td>31.30%</td>
<td>3.7099</td>
<td>57.89%</td>
</tr>
</tbody>
</table>

A perfect electric conductor (PEC) reflector was arranged between a human head and the driver of a folded loop antenna. Numerical results showed that the radiation efficiency can be enhanced and the peak SAR value can be reduced. The advantages of [23, 24] explained in [25]. In [25], SRRs proposed for SAR reduction. The antenna used in [25] is dipole antenna, the size of the antenna is very large and it is not suitable to mobile phones. The proposed head model is simple contain only one tissue. But in our paper we used more practical adult human head model, it consists three layers of skin, bone and brain, electrical properties taken from [9]. In [25] the author designed SRR for SAR reduction. However, we found that when these structures are operated at 900 MHz, the sizes of these structures are too large for cellular phone applications and SAR reduction is only 27%. In our paper, we proposed three models of sub wavelength resonators namely SRRs, SRs and OSRRs. We compared size and performance of resonators and results are given in Table 3. The OSRRs size is very small, it is suitable to cellular phone applications and SAR reduction is 57%. In [26], the authors also proposed CLL structure which is similar to SRR for antenna application. However, we found that when these structures ([25, 26]) are operated 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 [27]. However, we found that when the thin wires are operated at 900 MHz, the size is also too large for practical application. Because the OSRR structures are resonant due to internal capacitance and inductance, they are on a scale less than the wavelength of radiation. In this study, it is found that the OSRRs can be designed at 900 MHz while the size is similar to that of cellular phone.
4. CONCLUSION

We constructed metamaterials from periodical arrangement of resonators between mobile antenna and human head. By properly choosing geometrical parameters of SRRs, SRs, OSRRs the stop band can be shifted around GSM 900 MHz of the cellular phone. The SAR distributions in a simplified human head model with the presence of resonators are studied, and a significant reduction can be obtained. Among the three resonators SR size is small, and performance point of view OSRRs is good. Numerical results can provide useful information in designing communication equipments for safety compliance.

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REFERENCES


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