International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.10, No. 2 (2017), pp.59-70
http://dx.doi.org/10.14257/ijsip.2017.10.2.05

Peak SAR Reduction using Metamaterial Structure

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Abstract

In this paper, a metamaterial is designed to reduce the value of specific absorption rate (SAR). The finite-difference time-domain (FDTD) method with lossy-Drude model is adopted in this analysis. The method of SAR reduction is discussed and the effects of location, distance, and size of metamaterials are analyzed. By properly designing structural parameters of SRRs, the effective parameter permittivity & permeability are to be negative around 900 MHz for a cellular phone. This circular split ring resonator is printed on the glass epoxy (FR4 lossy) of dielectric substrate with relative permittivity (€r) of 4.3, thickness of 1.6 mm. Other parameters such as directivity, antenna gain, radiation pattern are also analysed. These results can provide useful information in designing safety mobile communication equipments compliant.

Keywords*: FDTD method, head model, metamaterials, split ring resonator, specific absorption rate (SAR).*

1. Introduction

Recently, there has been an increasing public concern about the health risk caused by electromagnetic (EM) waves emitted from cellular phones. These phones send their signals using very small surges of high-frequency EM waves, or microwaves, favored over most over the air telecommunication systems. The fundamental safety limits for the radio-frequency (RF) revelation are defined in terms of the immersed power per unit mass, which is expressed by the specific absorption rate (SAR) in watts per kilogram (W/kg) [1]. These protection guidelines are set in terms of the utmost mass-normalized rates of the electromagnetic energy deposition (SARs) for 1 g or 10 g of tissue.

SAR is the parameter employed to properly quantify the response of the biological structure in terms of incident and induced field of the energy absorbed and maintained inside the human body. It is the time derivative (rate) of the incremental energy (d*W*) absorbed by or dissipated in an incremental mass (d*m*) contained in a volume element (d*V*) of a given density (ρ) in equation 1 [2].

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dm}\right) \quad (1)$$

The SAR is expressed in units of watts per kilogram(W/kg) or, equivalently, in milliwatts per gram (mW/g). It can also be related to the induced electrical field using equation 2 [2].

$$SAR = \sigma E^2/\rho \quad (2)$$

Where, *E* is the electric field's root mean square (V/m), σ is the biological tissue's electrical conductivity (S/m) and ρ is the biological tissue's density (kg/m3).

The use of mobile phone has been increasing rapidly. As the technology is moving from wired to wireless, the electromagnetic pollution is increasing. Cell phones are

ISSN: 2005-4254 IJSIP

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 [3,4] the SAR must be below the limits. Some results have implied that the peak 1*g* averaged SAR value may exceed the safety limits when a mobile telephone is placed extremely close to the head.

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.

Recently, metamaterials, including electromagnetic band-gap (EBG) structures, have been proposed for handset antennas with low SAR characteristics [5]. Metamaterials combining a negative permittivity and permeability, i.e., negative index materials (NIMs), can be obtained by using tiny electrical circuits called split ring resonators and continuous wires as the metamaterial constituent units.

The specific absorption rate (SAR) in the head can be reduced by placing the metamaterials between the antenna and the head. In the case of studying the SAR reduction of an antenna operating at the GSM 900 band, the metamaterial parameter (i.e., the permittivity is €r< 0, hence, the refractive index is $n < 0$) and the effective medium would be set negative [6-7]. Hence, the effectiveness of different positions, sizes, and metamaterials with various parameters are also analyzed for SAR reduction.

CST MWS is a device used as a major simulation instrument based on the finite-integral time- domain technique (FITD). An unvarying meshing scheme was chosen to make the major computation devoted to inhomogeneous mark boundaries and aimed at the fastest and faultless results. Two-cut schemes are needed for a complete model to show the region with the closely compacted meshing onward to inhomogeneous boundaries.

2. Metamaterial Structure and Design

2.1 Simulation and Measurement of Specific Absorption Rate Reduction Using Proposed Maetametrial Structure on rectangular Microstrip patch at 900MHz

To design the Patch Antenna, first step is to calculate the required parameters which are involved in designing. After getting these required values, the simulated results are obtained by using CST-2010 Software. The rectangular patches are designed on the epoxy/glass substrate material. Simulated result of patch on different resonant frequencies are compared and presented in graphical form.

The figure 1 represents the structure of Rectangular Microstrip Patch Antenna at 900MHz whose specifications for designing are mentioned below:

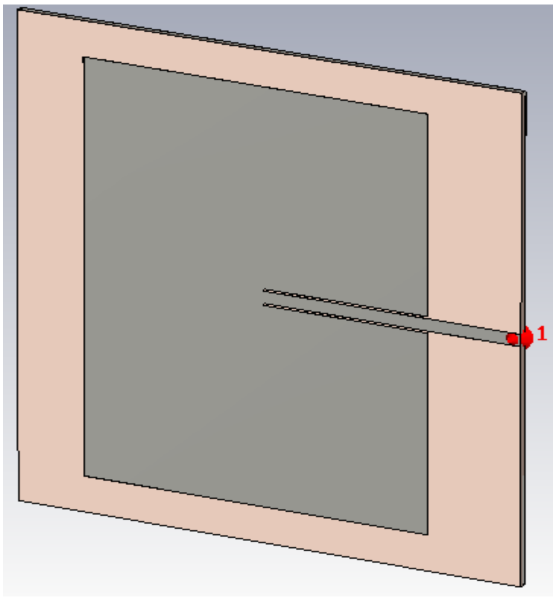

Figure 1. Rectangular Patch Antenna at 900MHz

Specifications:

1) Width of the patch = 102.38 mm.
2) Length of the patch = 77.78 mm.
3) Dielectric material is glass epoxy with dielectric material = 4.3
4) Substrate height = 1.6 mm.
5) Loss tangent = 0.02
6) Width of the Strip Line = 3 mm.
7) Length of the Strip Line = 58 mm.

Figure 2 shows the simulated Return Loss & Bandwidth of the Patch Antenna at 900MHz

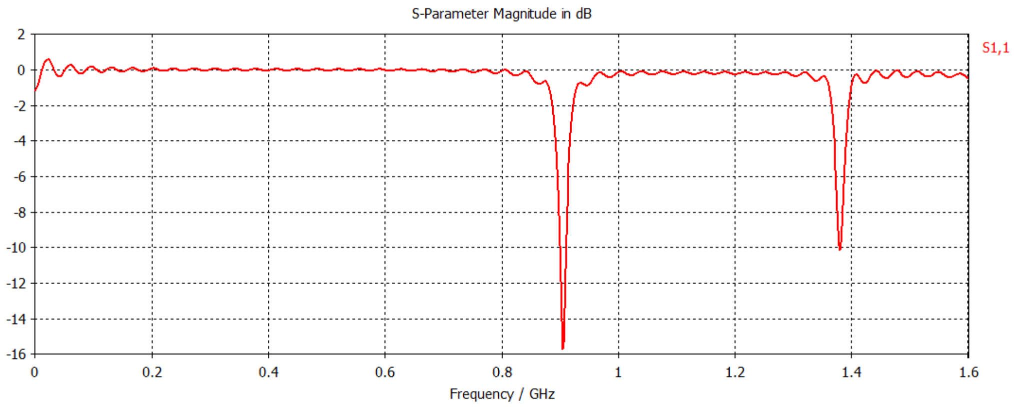

Figure 2. Simulated Result of RMPA Showing Bandwidth of 10.52MHz and Rreturn Loss of -15.9dB

The radiation pattern of an antenna is generally its most basic requirement because it determines the distribution of radiated energy in space. Once the operating frequency is known, the radiation pattern is the first property of an antenna that is specified. The Radiation Pattern of the RMPA operating at 900MHz is shown in Figure 3.

Figure 3 shows directivity of 5.785dBi and total efficiency of 53.6%.

The gain of an antenna is a basic property which is frequently used as a figure of merit. Gain is closely associated with directivity and directivity itself dependent entirely upon the shape of the radiation patterns of on antenna. Antenna Gain is inversely proportional to the Return Loss of the antenna.

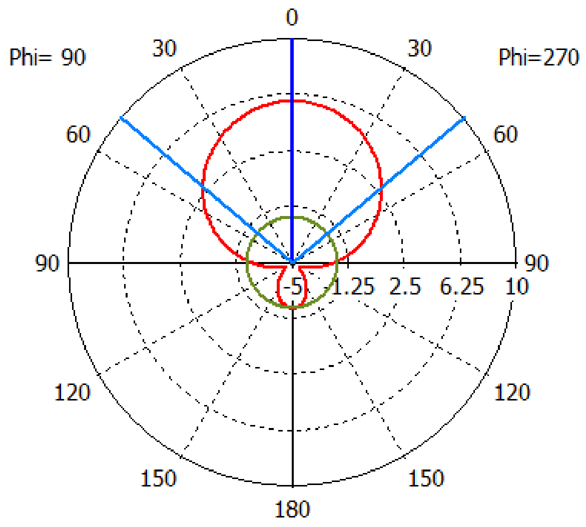

Figure 3. Radiation Pattern of RMPA

Circular shaped ring was designed for SAR reduction which is behaved as a metamaterial. Circular shaped ring is placed on the top of rectangular patch antenna. CSRR structure were used as the resonator model as shown in Figure 4. The resonators operated in the 900 MHz bands. The CSRRs contain combination of two rings each with gaps on the opposite sides in the middle part, pair of combination of two rings each having a gaps, 90 degrees between them and a pair of two individual ring, each with gap on the opposite sides. The entire outer most rings are connected to adjacent outer most rings except the individual rings. Dimension of circular shaped ring metamaterial is shown in the table 1

Table 1. Dimension of CSRRs

Component	Dimension
Width of the Outer circular rings	3 mm
Width of the inner circular rings	3 mm
Gap width of the outer and inner circular rings	3 mm
Width of the rectangular strips	3 mm

The gap between in the middle section of the circular ring is 8.2 mm while in the remaining section 2mm.

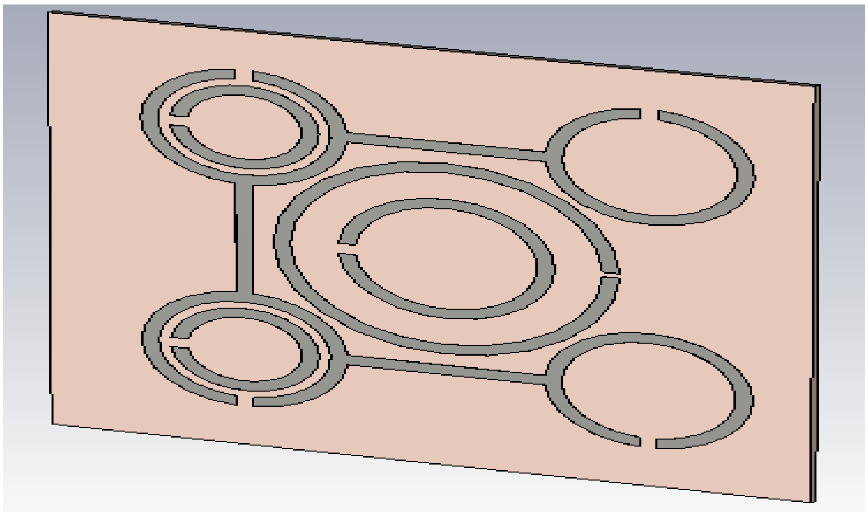

Figure 4. Structure of a CSRR at a Height of 3.2mm from the Ground Plane

After the metematerial is designed, its response is checked through NRW-Approach. In order to get more accurate approximation of the permittivity and permeability, the modified NRW Approach were studied and applied in this project. NRW approach is commonly used technique to determine the value of permittivity and permeability. Equations used for calculating permittivity & permeability using NRW approach:

$$\mu_r = \frac{2.c(1-v2)}{\omega.d.i(1+v2)} \tag{3}$$

$$\varepsilon_r = \mu_r + \frac{2.S11.c.i}{\omega.d} \tag{4}$$

Where,
$v1$ = S11 + S21
$v2$ = S21 - S11
ω = Frequency in Radian,
d = Thickness of the Substrate,
c = Speed of Light,
$v1$ = Voltage Maxima, and
$v2$ = Voltage Minima.

The obtained S-parameters from simulation results of CST are then exported to Microsoft Excel Software for calculating the value of the permittivity and permeability of the proposed design, using the Nicolson-Ross-Weir (NRW).

Figure 5 below shows graph of permeability. It can be seen that the parameter is negative at 900MHz.

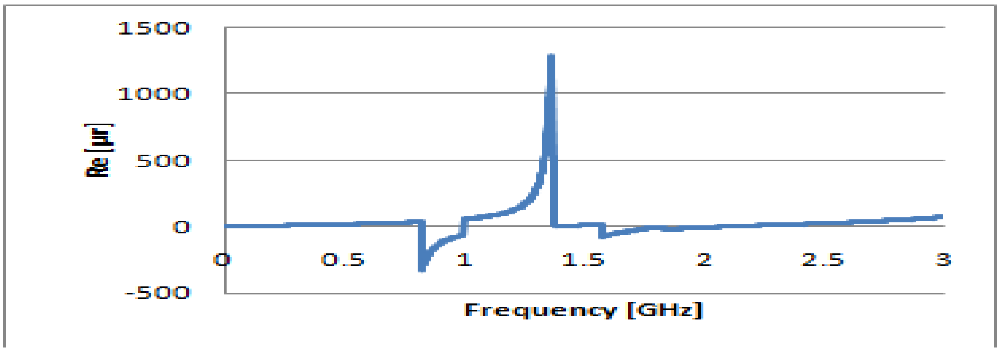

Figure 5. Graph of Permeability Showing Negative Value at 900 MHz

Similarly, the graph of permittivity is shown below and it can be seen that permittivity is negative at 900 MHz.

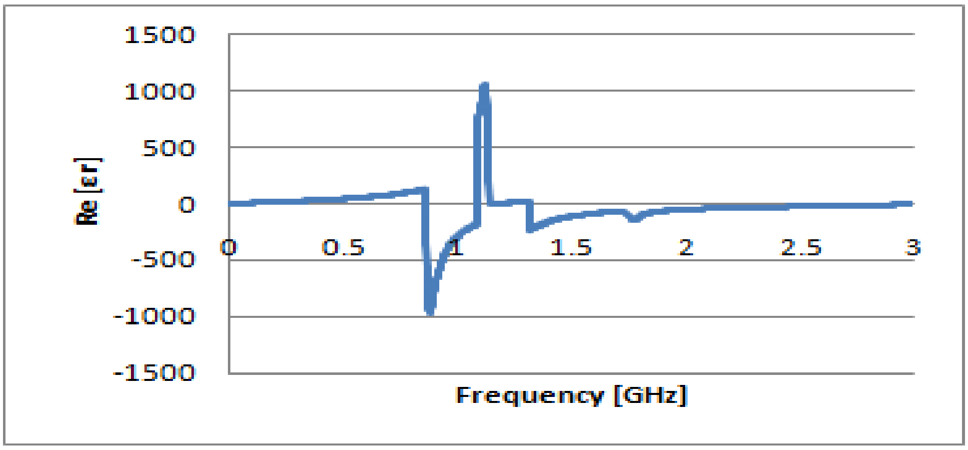

Figure 6. Graph of Permeability Showing Negative value at 900 MHz

The head models used in this analysis were obtained from a magnetic resonance imaging (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 the model [8-9].

To find SAR distribution, all we needed was a proper representation of cellular phone i.e., patch antenna operating at 900MHz, anatomical representation of head, proper alignment of phone and head, and a suitable design of metamaterials.

Finite Different Time-Domain (FDTD) was used to construct adult head modelling with the attachment of antenna and also to do a simulation in obtaining the SAR Distribution and SAR in Weight either 1gm or 10gm weight value, respectively. The proposed human head model for SAR calculation is as shown in Figure 7. It consists of four layers. The outer most layers in the human head is skin with thickness of 0.5cm, second layer represents the human fat with thickness of 0.5 cm, third 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 2.

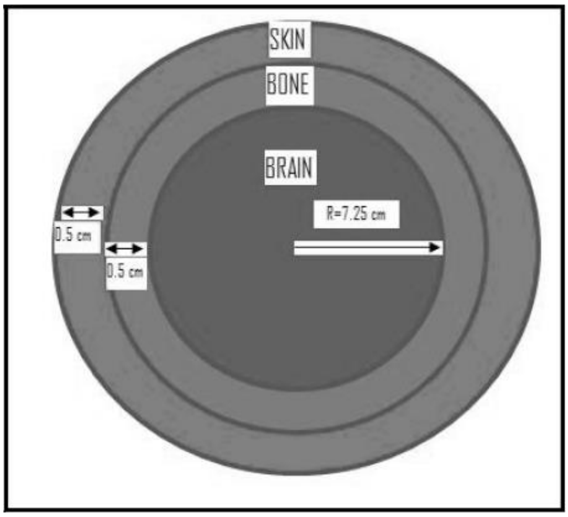

Figure 7. Layout of Human Head Model

Table 2. Electrical Properties of Different Components of Human Head Model

	Density'ρ', (kgm^{-3})	Conductivity 'σ', (Sm^{-1})	Relativepermittivity, (€r)
Skin	1100	8.013	31.29
Bone	1850	3.859	12.66
Fat	1100	0.585	4.60
Brain	1030	10.31	38.11

The designed metamaterial consists of circular split ring resonators in a particular design. This antenna is then attached to designed human head model and placed at a distance of 12.5mm from the head model as shown in figure 8

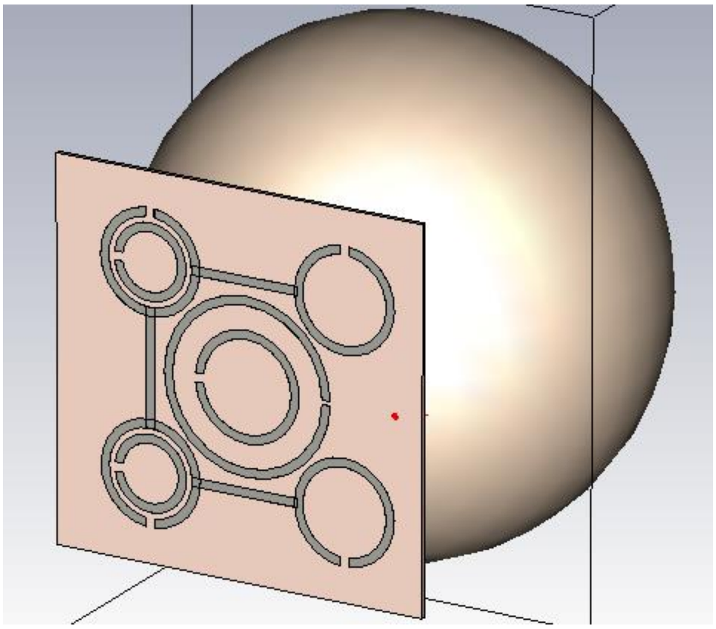

Figure 8. Structure of CSRRs with Proposed Human Head Model

The proposed CSRRs with proposed human head model is designed and simulated using the CST Microwave Software [10]. Figure 9 shows the simulated return loss of the proposed CSRRs with human model. The achieved simulated return loss of the proposed RMPA is -23.6dB at a frequency 0.904 GHz having the lower frequency (f_L) of 0.899GHZ and higher frequency (f_H) of 0.906GHz.

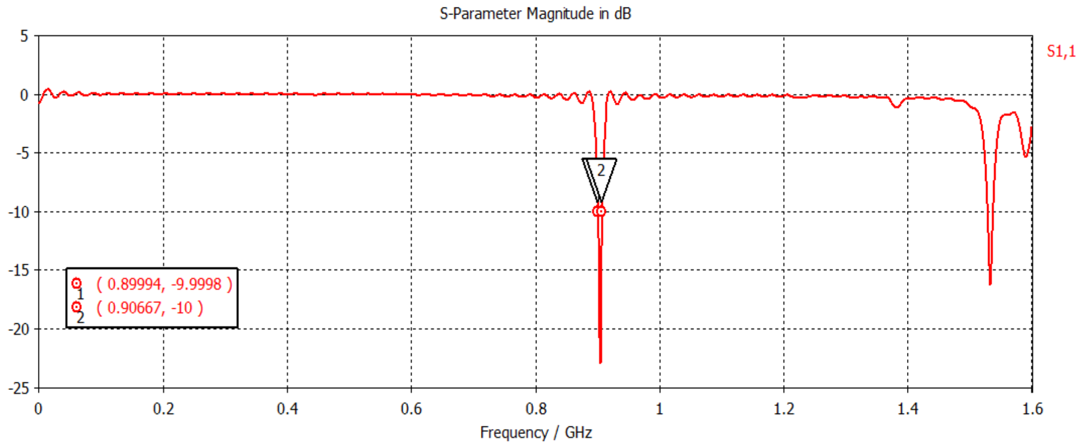

Figure 9. Simulated Return loss of Proposed CSRRs with Human Head Model at 0.904 GHz Showing Return Loss of -23.3dB

The 2D radiation patterns of proposed CSRRs with human head model at a frequency of 0.904GHZ in polar plot is shown in figure 10

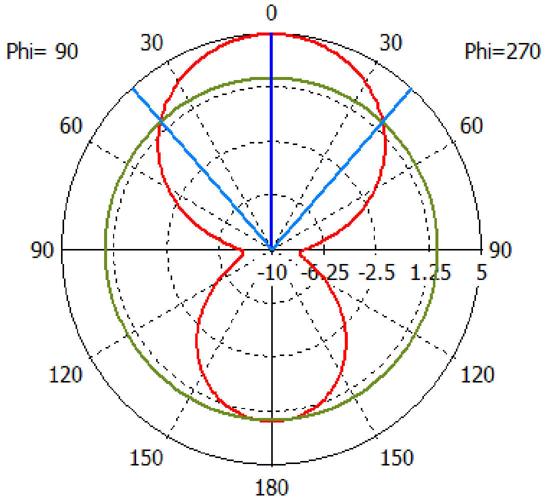

Figure 10. Simulated Radiation Pattern Result of the Proposed CSRRs with Human Head model at 0.904 GHz

The radiation efficiency and directivity at resonant frequency of 0.904 GHz are 79.23% and 4.873 dBi respectively. An important feature of the proposed CSRRs with human head model is to reduce the level of SAR. The simulated peak SAR for 1 gm value is 0.026 W/kg, and SAR 10 gm value is 0.0125 W/kg when the CSRRs is placed 12.5 mm away from the proposed human head model.

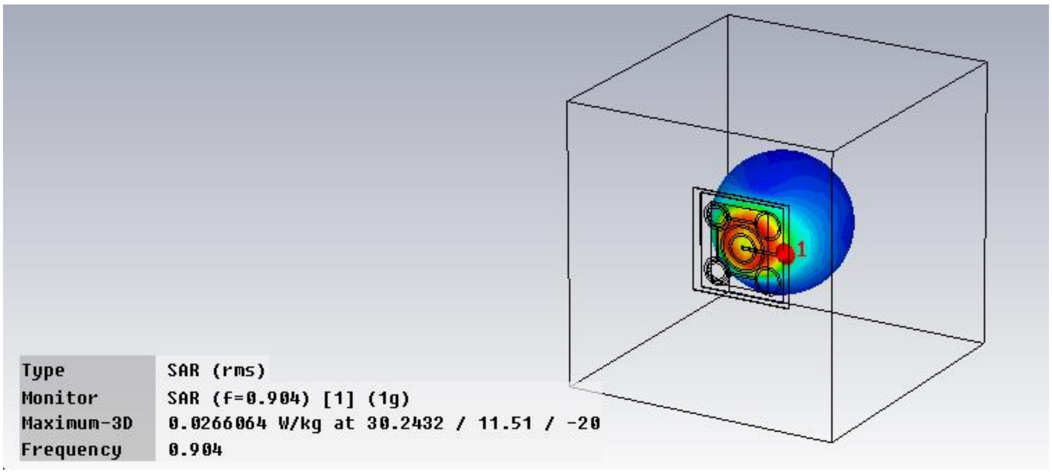

Figure 11. SAR 1g Value using Metamaterial Antenna Attached to Head Model

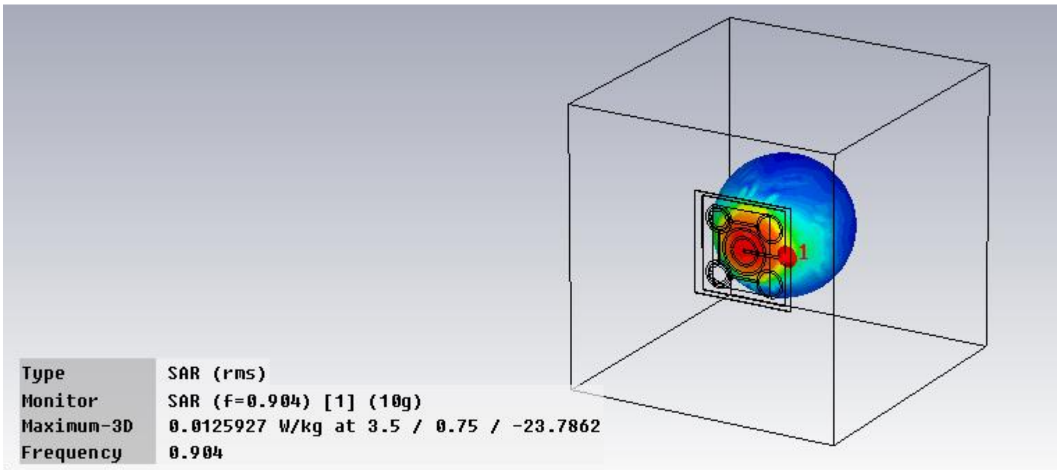

Figure 12. SAR 10g Value using Metamaterial Antenns Attached to Head Model

We can see that the obtained SAR values are much less than 1.6W/Kg which is as per Indian standards.

Table 3 shows the simulated SAR values of the proposed CSRRs with human head model with the different distance (D) between the metamaterial antenna and the human head model.

Table 3. Simulated SAR Values in the Human Head for Different values of *D*

Distance between CSRRs and human head model (D)	SAR value (W/kg)	
	1 gm	**10 gm**
10.0 mm	0.052	0.0239
12.5 mm	0.024	0.0125
15.0 mm	0.022	0.0124
17.5 mm	0.021	0.0109
20.0 mm	0.018	0.0103

From the table 3, it was clear that by increasing the distance (*D*) between the CSRRs and human head model, the SAR value is decreased.

It is clear from the simulation results that metamaterials can reduce the peak SAR successfully where the antenna performance is merely reduced.

3. Conclusion

A configuration of circular split ring resonator on the FR4 lossy substrate with a four layer of proposed human head model for GSM application has been investigated. It has been observed that return loss of the antenna is -23 dB at a resonant frequency of 900MHz with proper dimension of circular shaped structure which behaved as metamaterial. It is also investigated that SAR value is depending on the gap distance 'D' (distance between the CSRRs and the human head model) which is increased with the decrease in the distance D. So, it is advisory for the users to keep as much as possible distance between their head and mobile phone while using it.

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