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A New Design of Metamaterials for SAR Reduction

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The purpose of this paper is to calculate the reduction of specific absorption rate (SAR) with a new design of square metamaterials (SMMs). 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. SMMs have achieved a 53.06% reduction of the initial SAR value for the case of 10 gm SAR. These results put forward a guideline to select various types of metamaterials with the maximum SAR reducing effect for a cellular phone.

Keywords: FDTD method, head model, square metamaterials, specific absorption rate (SAR), Planar Inverted F Antenna

1. Introduction

THE ELECTROMAGNETIC energy absorption of the human tissues made by cellular phones has become a point of serious public deliberations due to possible health risks. The specific absorption rate (SAR), defined as:

$$SAR = \frac{\sigma\left|\vec{E}\right|^2}{\rho} = c\frac{dT}{dt}$$

is equivalent to the tissue heating rate, where the symbols σ for electrical conductivity, ρ for mass density, c for specific absorption rate and dT/dt for the changing rate of the temperature in body tissue have their typical meanings. Recent radiation protection standards [1-2] specify threshold values for averaged SAR averaged over tissue masses of 1 or 10 gm, respectively, which should not be exceeded by any cellular mobile phone apparatus. 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, the reduction of SAR value is an important issue of the portable devices.

Kivekas et al. (2004) investigated the antenna efficiency, bandwidth, and SAR as a function of a mobile phone's armature-associated parameters, such as length, thickness, width, and partition from the phantom [3]. This statistical study established that when the resonant frequency of the armature became equal to the resonant frequency of the antenna, the SAR increased while the radiation efficiency decreased.

In Okoniewski and Stuchly (1996), the authors analyzed the dependence of the exposure of the head on the antenna's radiation patterns using the FDTD method and comparing the SAR using various head models. A monopole antenna on a metallic box was considered at a frequency of 900 MHz [4].

The majority of the studies have used a finite-difference time-domain (FDTD) method for solving the electromagnetic problem and bio-heat equation for thermal modeling. There are various sources of uncertainty and variation in this kind of combined FDTD and temperature simulations [5-16]. Usually, the rise in temperature has been small so thermoregulatory response has been ignored, which may have led to overestimation. SAR values also depend on how they are actually calculated; because the description of SAR averaging in ICNIRP (1998) guidelines is somewhat vague, various different SAR averaging methods have been considered in several studies.

The ferrite sheet has proved to be a good material for reducing the SAR values [17, 18]. The consequence of ferrite sheet attachment to cellular mobile handset was also considered in [19]. This paper has claimed utilizing the mobile phone with a monopole antenna. The current from the monopole antenna flows on all surfaces of the box. Without altering the antenna performance, the ferrite sheet was used to suppress the current flowing in the handset box resulting in a significant reduction of the SAR. The reducing of the SAR values has recently been examined by the same method as in our previous published paper in [18]. It was found that the ferrite attachment reduces the SAR values due to the suppression of currents flowing on the front side of the cellular handset. Resistive cards (R-cards) sheet has also been discussed as a way to decrease the SAR values by reducing the radiation toward the human head [20].

Different methods have been proposed over the last 20 years to reduce the SAR produced by emissions from handset antennas to levels below the current maximum exposure levels of the international standards including auxiliary antenna elements, ferrite loading, EBG/AMC surfaces and low SAR handset antenna techniques. This paper focuses on an antenna design utilizing new metamaterial developments for SAR reduction.

Recently, metamaterials, including electromagnetic band-gap (EBG) structures [21], have been proposed for mobile phones with peak SAR descriptions [22]. According to these studies, the overall dimensions of the antennas with metamaterials were larger than those of the wireless terminals.

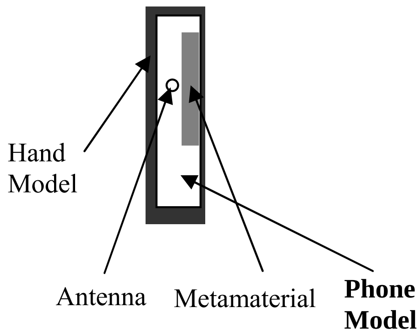
Nowadays, many are interested in metamaterials with split ring resonator (SRR) structure that was proposed to reduce the SAR value [23]. The negative permittivity can be obtained by arranging the metallic thin wires periodically

[24]. On the other hand, an array of SRR can exhibit negative effective permeability. The metamaterials are designed on circuit board so it may be easily integrated into the cellular phone. Simulation of wave propagation into metamaterials was proposed in [23-25]. This method is a helpful approach to study the wave propagation characteristics of metamaterials [26-27] and has been developed more with the perfectly matched layer (PML) and extended to the three-dimension problem [27].

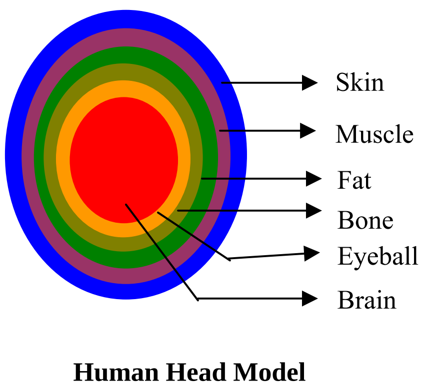
Specifically, the problems to be solved in SAR reduction need a proper representation of the cellular phone, anatomical representation of the head, alignment of the phone and the head, and a suitable design of the metamaterials. Metamaterial techniques seem promising options in terms of low cost and ease-of implementation in mobile phones to reduce the SAR.

2. Methodology

Computer Simulation Technology Microwave Studio (CST MWS) is a device used as a major simulation tool dependent on the finite-difference time-domain method (FDTD). An unvarying meshing scheme was chosen to make major computation which is devoted to inhomogeneous mark boundaries for the fastest and faultless result. Two-cut schemes are needed for the complete model to indicate the region with closely compacted meshing onward to inhomogeneous boundaries. Here the least and highest mesh sizes were 0.3 mm and 1.0 mm, respectively.



(a)



(b)

Fig.1. Head-Phone model for SAR calculation.

As a result, the total number of mesh cells of 2,122,164 was generated and the simulation time was 1208 seconds, including mesh generation for each effort as on an Intel Core TM 2 Duo E 8400 3.0 GHz CPU with 4 GB RAM system, for the complete model. It is noted here that at first the materials are placed between the antenna and a human head, and then all of these are replaced by a metamaterial. For this research, the SAM head model was considered, and it comprises about 2,097,152 cubical cells at 1 mm resolution. Here Figs.1.(a) & (b) represent a portable telephone model with head model [28], and it was considered in SAR calculation.

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 this model [9, 21]. Numerical simulations of SAR value were performed by the FDTD method. The parameters for FDTD computation in this paper were as follows. The simulation domain was 128 × 128 × 128 cells. The cell sizes were set as $\Delta x = \Delta y = \Delta z = 1$ mm. The computational domain was terminated with 8 cells perfect matched layer (PML). A PIFA antenna was modeled by thin-wire approximation.

3. Proposed metamaterial designing construction and analysis of SAR

The SAR in the head is reduced by placing the square metamaterials (SMMs) between the antenna and the head. The SMMs are on a scale less than the operating wavelength. The structures are resonant due to their internal capacitance and inductance. The stop band can be designed at the operation bands of cellular phone radiation. The SMMs are designed on a printed circuit board to allow them to be easily integrated into the cellular phone. The SMMs dimensions are obtained by arranging the sub-wavelength resonators periodically.

3.1. Metamaterial construction and design

This paper establishes that, using FDTD analysis, SMMs can reduce the peak SAR 1 gm and SAR 10 gm in the head. In this section, the SMMs are evaluated in the cellular phone 900 and 1800 MHz bands. Periodically arranged SRRs can work as SMMs. The SRR's structure involves two conductive material concentric square rings. Both square rings have a gap, and each ring is placed opposite to the gap on the other ring. The schematic of the SRRs used in this study.

To build the SMMs for SAR reduction, SRR structures were used as the resonator model, as shown in Fig.2. The resonators operated in the 900 MHz bands. The SRRs contain two rings, each with gaps on the opposite sides [22]. The SRRs were introduced by Pendry et al. (1999) [23], and subsequently used by Smith et al. (2000) to synthesize the first left-handed artificial medium [24]. The metamaterials in this work were designed with periodic SRRs arrangements to reduce the SAR value. By properly designing the SRR structure parameters, a negative effective medium parameter can be achieved for the 900 and 1800 MHz bands. The fabricated SRRs are shown in Fig.3.

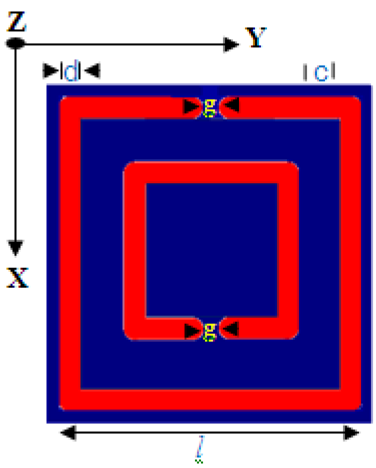


Fig.2. Structure of the SRRs used in SAR calculation.

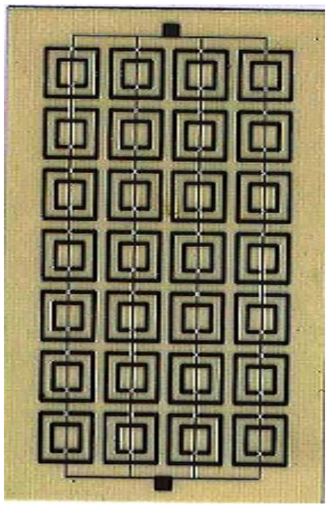


Fig.3. Fabricated SRR arrays.

4. Numerical results & discussion

The designed SRRs were placed between the antenna and the human head. This reduces the SAR value. In order to study SAR reduction by SRRs at the GSM 900 band, various relative positions, sizes, and metamaterials were also analyzed by using the FDTD method along with a detailed human head model. The antenna was oriented parallel to the head axis and the distance between the antenna and the head axis varied from 5 mm to 20 mm. Finally, 20 mm was chosen as base for comparison of different metamaterials. The output power of the mobile phone model must be specified 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 practice, the output power of the mobile phone does not exceed 250 mW under normal circumstances, while the maximum output power, when the base station is far away from the mobile station (cellular phone), can be up to 1 W or even 2 W without a metamaterial, 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 20 mm away from the human head model. This is better than the results reported in [17], and [19], which are 2.17 W/kg and 2.28 W/kg, respectively, for SAR 1 gm. This is because the mobile antenna position, size and type are different in this study. This SAR value is also better than the result reported in [22], which is 2.43 W/kg for SAR 1 gm. Again, this is achieved using different radiating power and antenna. The results imply that only suppressing the maximum current on the front side of the 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 metamaterial and it is because the electromagnetic source is being moved away from the head.

To study the effect of SAR reduction with the use of new SMMs, the radiated power from the PIFA antenna with μ =1 and ε = -3 mediums was fixed at 600 mW.

Table 1. Effects of Metamaterial on Antenna Performances and SAR reduction at 900 MHz

	Z_R (Ω)	P_R (mW)	P_{abs} (mW)	SAR 1 gm (W/Kg)
Without metamaterial attachment	63.39+j94.53	600	268.83	2.002
μ= 1, ε = -3	51.43+j99.68	514.6	211.95	1.0697
μ= 1, ε = -5	54.12+j95.25	532.8	238.45	1.5635
μ= 1, ε = -7	59.25+j96.14	541.9	251.34	1.732

Different negative medium parameters were analyzed for SAR reduction efficiency. We positioned the negative permittivity media between the antenna and the human head as mentioned before. Initially, the plasma frequencies of the mediums were set to $\omega_{pe} = 9.309 \times 10^9$ rad/s. This led to media with μ = 1 and ε = -3 at 900 MHz. The media with even larger negative permittivity (μ= 1, and ε = -5; μ= 1, and ε = -7) were also studied. We set $\Gamma_e = 1.2 \times 10^8$ rad/s, meaning the media have losses. Simulation results of SAR value and antenna performance are compiled in Table 1. The peak SAR 1 gm goes down to 1.0697 W/kg with μ = 1 and ε = -3 mediums. Impedance is also affected by the metamaterials. Compared to the control experiment without metamaterials, the radiated power is reduced by 13.9% while the SAR is reduced by 53.43%. With the use of air medium, less SAR reduction is achieved, though, the radiated power from the antenna is basically unaffected.

5. Experimental verification

The SAR measurement is carried out using the COMOSAR measurement system. The COMOSAR system consists of the following items: original computer to control all the system, 6 axis robot, data acquisition system, miniature E-field probe, phone holder and head simulating tissues. The head phantom is filled with a liquid with dielectric properties selected based on IEEE standard 1528, which are $\varepsilon_r = 41.5$ and $\sigma = 0.97$ S/m for 900 MHz and $\varepsilon_r = 40$ and $\sigma = 1.4$ S/m for 1800 MHz. The head phantom set-up includes a cover, which prevents the evaporation of the liquid. Without the inclusion of SMMs, the simulated and measured SAR values of the head model are shown in Fig.4.

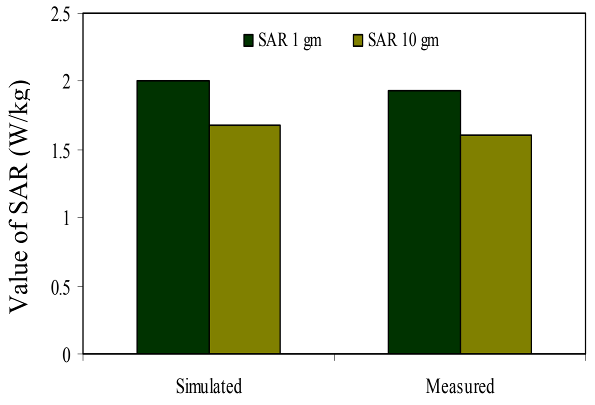


Fig.4. Compared SAR values in simulation and measurement results without the SMMs attachment.

Fig.4. shows that the simulated SAR value is greater than 3.29% for SAR 1 gm and 3.82% for SAR 10 gm, which is due to the fact that the distance between the head and phone model has not been correctly situated for the measurement stage. In addition, the distance between the source and internal surface of the phantom position affects SAR. For a 5 mm distance, a positioning uncertainty of ± 0.5 mm would produce a SAR uncertainty of $\pm 20\%$. Accurate device positioning is therefore essential for accurate SAR measurements.

Fig.5. illustrates how to set up the apparatus for cheek and tilted position measurement. Fig.5.a) shows cheek position of the measurement & Fig.5.b) is denoted by 15° tilted position. The antennas with the SMMs are in contact with the SAM phantom head. During the measurement, the radiation power has been set to the maximum for the phone being tested (as required by the standard), that is 33 dBm for GSM 900.

In this research the simulated & measured SAR obtained using the tilted position for the SMMs with the antenna revealed simulated and measured SAR values of 0.737 W/kg and 0.639 W/kg for SAR 10 gm, respectively, using the antenna with SMMs. The simulated and measured SAR differed by 6.37% for SAR 10 gm. Regarding the difference in the absolute values of peak SAR, the phone model casing for simulation was different from the case for measurement. In addition, Scotch tape was used to attach the SMMs and antenna in measurement stages. The simulated and measured results also differ because the parameters for the measurement system change with water evaporation and temperature.

In addition, the SAR measurement of the antenna with SMMs attached in the cheek position was considered, which yields 0.696 W/kg for SAR 10 gm. The greater SAR values measured for the cheek position than for the tilted position can be attributed to the influence of the ground plane on the distribution of surface currents; consequently, the power deposited inside the head is higher for the GSM frequency band.

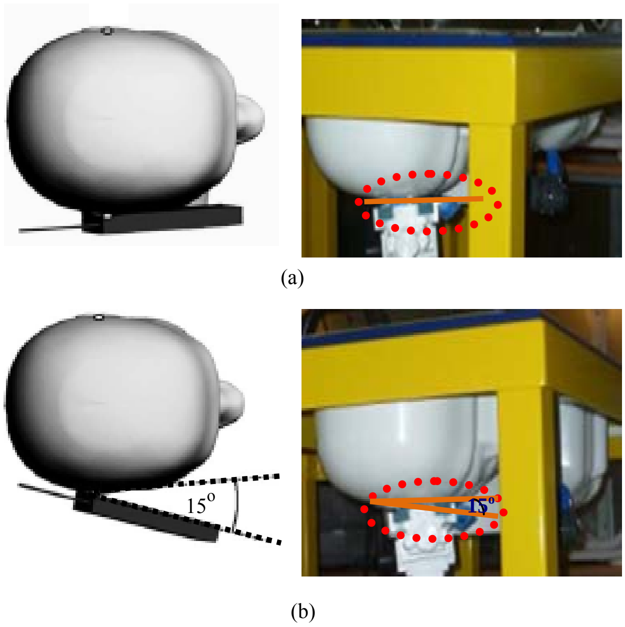


Fig.5. Apparatus setup for real measurement system in: a) cheek position, b) tilted position

6. CONCLUSION

In order to study the process of EM energy absorption between an antenna and the human head with the new SMMs, meticulous and intensive experiments were carried out in this paper. The newly developed SMMs attachment in the phone model led to a SAR value of about 0.639 W/kg for SAR 10 gm and 1.0623 W/kg for SAR 1 gm. A practical conclusion that can be drawn from the compared numerical and experimental results is that the new SMMs reduce the better SAR reduction in human head.

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