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Technical note

Electromagnetic (EM) absorption reduction in a muscle cube with metamaterial attachment

M.R.I. Faruque [a,b,*], M.T. Islam [a], N. Misran [a,b]

[a] Institute of Space Science (ANGKASA), Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[b] Dept. of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia

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ABSTRACT

The purpose of this paper is to calculate the specific absorption rate (SAR) reduction in a 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. In this paper, we have designed the single-negative metamaterials from a periodic arrangement of split ring resonators (SRRs). By properly designing the structural parameter of the SRRs, the effective medium parameter can be tuned negative at the 900 MHz and 1800 MHz bands. Numerical results concerning the SAR values in the muscle cube in the presence of resonators exhibit significant SAR reduction. These results can provide useful information when designing safety-compliant mobile communication equipment.

1. Introduction

Portable terminal devices are used widely in human life. Because the usage of mobile devices increases every year, an extensive study on the health risks caused by hazardous electromagnetic fields is in progress. The specific absorption rate (SAR) is the parameter typically used to evaluate power absorption in the human head. Radio frequency (RF) safety guidelines have been issued to prevent excessive electromagnetic field exposure in terms of SAR [1]. The exposure of the human head to the near field of a cellular phone can be evaluated by measuring the SAR in a human-head phantom, or through calculations using a human-head numerical model. Therefore, it is important for portable devices to have a reduced SAR value. Previously, the insertion of a ferrite sheet between the antenna and the human head, the position of the antenna feeding point, the use of conductive materials (such as aluminium), and electromagnetic band gap (EBG) structures to design high performance devices were proposed as methods of reducing the SAR value [2–4].

The applications of metamaterials are shown to be wide-ranging, encompassing electronics telecommunications, sensing, medical instrumentation, and data storage. Recently, much interest has been focused on metamaterials using a split ring resonator structure to further reduce the SAR value [5]. Negative permittivity can be obtained by arranging the metallic thin wires periodically [6–11]. On the other hand, an array of split ring resonators (SRRs) can exhibit negative effective permeability. The transmission characteristics are affected by the width of the SRRs as well as the combination of changing both width and separation of the SRRs. SRR width affects the inductance of the loop, with smaller width corresponding to increased inductance, and therefore, a smaller magnetic response. The reduction of the gap size reduces the magnetic response; however, this has a much smaller effect than the influence shown by the variation in ring separation. In Ref. [5], the SRRs designed operated at 1800 MHz and were used to reduce the SAR value in a lossy material. The metamaterials are designed on a circuit board so that they may be easily integrated into the cellular phone. Simulation of the wave propagation into metamaterials was proposed in Refs. [5–7]. The authors utilized the FDTD method with lossy-Drude models for simulation. This method is a helpful approach to studying the wave propagation characteristics of metamaterials [8,9] and has been further developed with use of a perfectly matched layer (PML) and can be extended to a three-dimensional problem [7].

In this work, the muscles that are underneath the skin of the face will be considered in order to analyse the SAR reduction. At first, the SRRs are used to reduce the EM interface between a Planer Inverted F-Antenna (PIFA) and a muscle cube. By properly choosing the geometry parameters of the SRRs, the permeability can be negative at 900 MHz and 1800 MHz. The SAR circulation in the muscle tissue is studied in the presence of the SRRs. To explore

* Corresponding author at: Dept. of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia. Tel.: +60 102938061.
E-mail addresses: rashedgen@yahoo.com (M.R.I. Faruque), titareq@yahoo.com (M.T. Islam), bahiah@vlsi.eng.ukm.my (N. Misran).

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Table 1
Electrical properties of the materials used for simulation.

Phone materials	ε_r	σ (S/m)
Circuit board	4.4	0.05
Housing plastic	2.5	0.005
LCD display	3.0	0.02
Rubber	2.5	0.005
SAM phantom head		
Shell	3.7	0.0016
Liquid at 900 MHz and 1800 MHz	40	1.42

the influence of the SRRs on the antenna, the radiated power and radiation impedance of the antenna, different positions, sizes, and negative medium parameters of metamaterials for effectiveness of SAR reduction are also analysed. Numerical results are established to confirm the effect of SAR reduction.

This paper is structured as follows: Section 2 describes the use of the materials and the method of numerical simulation. Section 3 describes the design of the SRRs and the simulation of the interaction between the handset antenna and the SAM phantom head. The SAR calculation in the muscle cube is described in Section 4 while Section 5 concludes the paper.

2. Materials and methods

Antenna radiation and its interaction with the head tissues (muscle cube) using the FDTD method from the CST Microwave Studio (CST MWS) EM software is utilized in this paper. A complete handset model composed of a circuit board, LCD display, keypad, battery, and housing was modelled in the simulation. The relative permittivity and conductivity of the individual components were set to comply with industrial standards. In addition, the definitions in Refs. [10–13] were adopted for the material parameters involved in the SAM phantom head. In order to accurately characterise the performance over a broad frequency range, dispersive models for all of the dielectrics were adopted during the simulation [2–4]. The electrical properties of the materials used for the simulation are listed in Table 1.

CST MWS software, which utilizes the finite integral time-domain technique (FITD) proposed by Weiland in 1976 [2] was used as the main simulation instrument. With the use of permutations in the perfect boundary approximation (PBA) and thin sheet technique (TST), significant development in geometry approximation and computation speed is achieved with highly accurate results. A non-uniform meshing scheme was adopted so that a major computation endeavour was dedicated to regions along the inhomogeneous boundaries for fast and perfect analysis.

The head model used in this study was obtained from the MRI-based head model provided by the whole brain atlas website. Various types of tissues were involved in this model: air, skin, muscle, fat, bone, cerebrospinal fluid (CSF), brain matter (grey and white), blood, cartilage, vitreous humour, lens, and eye sclera. However, we have only considered muscle cube tissue in this paper. Table 2 shows the muscle cube tissue dielectric properties [5–7]. Fig. 1 shows a heterogeneous, realistic head model used for the FDTD calculation. The electrical properties of the muscle tissue were taken from Refs. [4–6]. Numerical simulation of the SAR value

Table 2
Tissue properties used for the muscle cube: ρ, σ, and ε_r values defined at 900 MHz and 1800 MHz.

Tissue type: muscle cube in human head			
	σ (S/m)	ε_r	ρ (kg/m^3)
900 MHz	1.11	51.8	1040
1800 MHz	1.53	49.4	1040

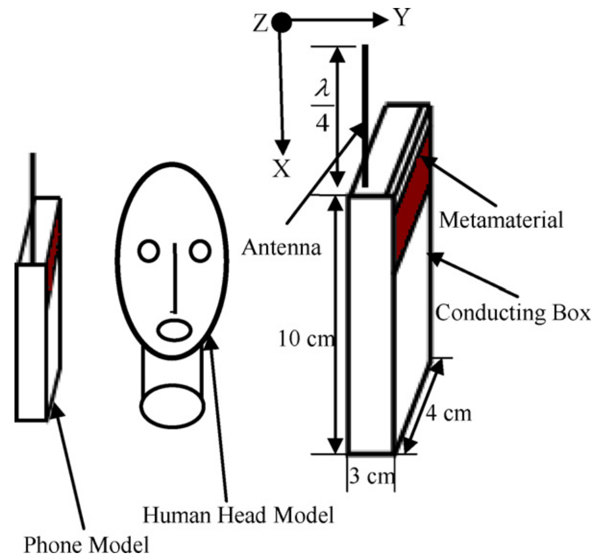

Fig. 1. The head and antenna model for the SAR calculation.

was performed using the FDTD method. The parameters for the FDTD computation were as follows. In our lossy-Drude simulation model, the domain contained 128 × 128 × 128 cells. The cell sizes were set as $\Delta x = \Delta y = \Delta z = 2.0$ mm. The computational domain was terminated with 8 cells [18] which formed a perfectly matched layer (PML). The antenna was designed such that the S_{11} response was less than −10 dB across the frequency band of interest. The SAM phantom head was then included for SAR calculation using the standard definition of:

$$\mathrm{SAR} = \frac{\sigma}{2\rho}E^2 \quad (1)$$

here E is the induced electric field (V/m), ρ is the density of the tissue (kg/m^3), and σ is the conductivity of the tissue (S/m), which is expressed by SAR in W/kg. The resultant SAR values averaged over 1 g and 10 g of tissue in the head were denoted as SAR 1 g and SAR 10 g, respectively. These values were used as a benchmark to evaluate the effectiveness of the peak SAR reduction.

3. Design and simulation of the SRRs

To construct the metamaterial for the SAR reduction, we have proposed one model of resonators, namely, the SRRs shown in Fig. 2. We designed the resonators for operation at the 900 MHz band. SRRs were introduced by Pendry et al. in 1999 [10] and subsequently used by Smith et al. in 2000 for synthesis of the first left-handed artificial medium [11]. A lot of efforts worldwide have been devoted to studying single-negative metamaterials (SNMs) and double-negative metamaterials (DNMs) and their properties [14] and applications in antennas [4] and other microwave devices. Metamaterials with a negative permeability medium can be obtained by arranging the SRRs periodically. The SRRs considered in this paper consisted of two concentric square rings, each with gaps appearing on the opposite sides. In Fig. 2, the structures of the resonators are defined by the following structural parameters: the ring thickness c, the ring gap d, the square ring size l, the split gap g, and c_0, the speed of light in free space. The resonant frequency ω is very sensitive to small changes in the structural parameters of the SRRs. The frequency response can be scaled to a higher or lower frequency depending on the proper selection of these geometry parameters by utilising the following equation [7]:

$$\omega^2 = \frac{3lc_0{}^2}{\pi \ln(2c/d)r^3} \quad (2)$$