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Enhancing antenna performance and SAR reduction by a conductive composite loaded with carbon-silica hybrid filler

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ABSTRACT

In this paper, we describe a technique for reducing the specific absorption rate (SAR) and human effects on antenna performance, based on combined use of rubber conductive composite loaded with carbon-silica hybrid filler used like a single director and a resonant half wave dipole. The finite-difference time-domain method was used to evaluate SAR and antenna performance for different antenna-composite configurations and distances. Bandwidth, gain, and radiation efficiency for different antenna-composite configurations were compared. It was found that the presence of a conductive composite loaded with carbon-silica hybrid filler can effectively reduce maximum SAR value (up to 70%) in a human head model, increasing the radiation efficiency (up to 67%) and the bandwidth (up to 110%) of the antenna.

1. Introduction

Modern society is characterized by an everincreasing demand for communications, leading to a continuous expansion of wireless communication devices. Most of wireless communication devices (mobile phones, tablets, etc.) are placed very close to the user's head or body, hence the antenna in close vicinity to the user. Therefore, current evolution of wireless personal communications has necessitated a comprehensive understanding of electromagnetic (EM) interactions between wireless device antennas and the nearby human body [1]. This interaction is focused on two areas of scientific interest. The first area is the antenna performance. The proximity of the user's head or body to the wireless device has several consequences, such as modification of the antenna radiation patterns, input impedance variation, detuning of the resonance frequency, etc. The second area referred is health hazards. The questions concerning health hazards have necessitated a more thorough evaluation and characterization of the specific absorption rate (SAR) in the human tissue [1].

During the last several years, many efforts have been done to reduce SAR values [2–4] and such human body effects on antennas performance [5,6]. Several different methods for reducing SAR values in the human tissue of a wireless device antenna have been proposed: (i) increasing the distance between the antenna structure and human head [7–10], or changing the antenna position, or the feeding point [11]; (ii) using metamaterials [12], including electromagnetic band-gap structures [11–14]; (iii) using a ferrite material [15], or a graphene-type absorbing material [10] and (iv) including a reflector element along with the main antenna [16], a metal backing [4], or cavity-backed antenna [5]. However, the above reflecting or absorbing methods also degrade the antenna performance at the same time. In this paper, we propose a natural rubber conductive composite loaded with a carbon-silica hybrid filler used like a single director to improve the gain performance, enhance antenna bandwidth and reduce SAR values (in human head or body). Moreover, the proposed conductive composite can be directly integrated with wireless device or as a protecting case.

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2. Materials, methods and models

2.1. Composite preparation and characterization

The composition of the natural rubber (NR) conductive composite in phr (parts in wt per 100 parts in wt of dry rubber) was as follows: natural rubber-SMR 10 (100.0 phr), carbon-silica hybrid filler (70.0 phr), N-*tert*-Butyl-2-benzothiazolesulfenamide (1.5 phr), zinc oxide (3.0 phr), stearic acid (2.0 phr), and sulphur (2.0 phr). The carbon-silica hybrid filler was prepared by modification of electro conductive Printex XE-2B carbon black with the needed amount of silicasol, corresponding to 7% silica. The vulcanization of the NR based compounds was carried out on an electrically heated hydraulic press. Finally, thin sheet (dimensions 60.0 mm × 190.0 mm, thickness 2.8 mm) of vulcanized rubber compounds was obtained.

The electromagnetic parameters of the composite material was measured by the resonant perturbation method [17]. According to the resonant perturbation method, the tested sample was introduced into a resonator, and the EM parameters of the sample were deduced from the change in the resonant frequency and quality factor of the resonator. The real part of the relative permittivity (ε_r') is 436.74 and imaginary part (ε_r'') is 20.63 at frequency 0.94 GHz. Measured value of ε_r'' was used to determine the effective conductivity of the composite sample. The effective conductivity of composite is 1.078 S/m.

2.2. Evaluation methods

The SAR spatial distribution in a human head model was computed using a finite-difference time-domain (FDTD) numerical technique. The 12-field components approach was used to calculate SAR in the voxel. All results were normalized to net input power level 1W. FDTD was chosen because it is stable and accurate, does not require enormous computational resources, and its advantages are listed in IEEE Standard C95.1 [18].

All simulations were accomplished with a commercial FDTD program (XFDTD, Remcom Inc., State College, PA, USA) under the following conditions: The uniform mesh FDTD technique was used to calculate the SAR and input characteristics of the antenna. A cell size of 1 mm was used. The FDTD mesh was round with 7 layers absorbing boundary type perfect matched layer. Each antenna-composite configuration was pulse excited with Gaussian pulse width 61.632 ps and sinusoid at a frequency, corresponding to first resonant frequency, consecutively. Computations were terminated after a steady state was reached.

2.3. Numerical models

2.3.1. Wireless device model

A large variety of antenna types, shapes, and sizes are used in wireless devices [19]. Carrying out a study that includes all antenna types, shapes, and sizes is a formidable task and is not required since many of them have similar efficiency, bandwidth, and gain characteristics. Hence, in order to evaluate the influence of conductive composite loaded with carbon-silica hybrid filler on antenna performance and SAR reduction, it was necessary to reduce this large variety of antenna types to a simple configuration (in order to derive the fundamental interaction properties). For this reason, we have based our investigation on a half wave dipole antenna, because the most basic starting point for a mobile terminal antenna is a half wave dipole [20]. The numerical model of our antenna is based on the reference dipole for 0.9 GHz frequency, described in IEEE Standard 1528 [21] and in European Standard EN 62209-1:2006 [22]. The dimensions of reference dipole at 0.9 GHz are – length 149.0 mm and diameter 3.6 mm and corresponded to resonant dipole. The resonant dipole was chosen because dipoles with resonant length yield higher SAR values than those of nonresonant length [20]. The numerical antenna model was modeled as a perfect electrical conductor (PEC). During the calculations, the antenna was placed exactly on the lattice of FDTD in order to avoid staircase modeling of the antenna.

2.3.2. Head model

The head model that was used in our research is a specific anthropomorphic mannequin (SAM). The dielectric properties of the equivalent head tissue used in SAM are those defined in [21,22] at 0.9 GHz – relative permittivity 41.5, conductivity 0.90 S/m, and mass density 1000 kg/m^3, while the dielectric properties of the shell and ear spacer were defined as follows: relative permittivity 3.7, conductivity 0 S/m, and mass density 1000 kg/m^3.

2.3.3. Head and antenna alignment

After SAM importation into FDTD mesh, it was rotated 60° around y-axis and translated so that the longitudinal axis of the dipole aligned with M-LE (mouth–left ear) line of SAM. Additional translation of SAM was made to achieved coincidence between the feeding point of the dipole antenna and LE point on SAM surface. The distance between the dipole feeding point and the nearest point of the equivalent head tissue of SAM was established at 23 mm, which corresponded to 17 mm to the outer surface of SAM shell.

2.3.4. Composite model

The composite model used in our research was a homogeneous rectangular block. The dimensions of the composite models and their orientations in computational mesh were 2.8 mm (x) × 14 mm (y) × 124 mm (z) and 2.8 mm (x) × 14 mm (y) × 149 mm (z). The obtained numerical natural rubber carbon-silica (NRCS) composite models were denotes as NRCS 124 and NRCS 149, respectively. The length of the models was chosen on the base of a study performed with dipole structure combined with directors and/or reflectors [16]. The electromagnetic parameters of conductive composite models used in FDTD simulations were defined at a frequency 0.94 GHz as follows: real part of relative permittivity 436.74 and conductivity 1.078 S/m, based on measured values from Section 2.1.

3. Results and discussion

3.1. Antenna performance

3.1.1. Effects of SAM, composite's size and position on antenna performance

To illustrate how SAM, size, and position of the conductive composite loaded with a carbon-silica hybrid filler affect antenna performance we simulated the reference dipole antenna placed at a distance of 17 mm from outer surface of SAM shell. Next, we introduced a model of composite NRCS 124 and NRCS 149, consecutively. The composite was placed at distances 2.0, 6.7 and 13.7 mm from the antenna. The antenna was placed between SAM and the composite. For comparison, we introduced a model of metal plate with same dimensions as NRCS124 and NRCS149. The obtained numerical models were denoted as PEC 124 and PEC 149, consecutively.

Bandwidth (BW) at reflection coefficient magnitude lower than −10 dB and resonant frequencies of the reference dipole in free space and in the presence of SAM are listed in Table 1. In Table 2, bandwidth and resonant frequencies of the reference dipole with composite and with metal are shown.