Application of EBG Substrate to 4G Mobile Antenna for Power Absorption Reduction in Human Head

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Abstract — The present study investigates the performance of a dipole antenna on an electromagnetic band-gap (EBG) substrate toward low specific absorption rate (SAR) antenna for 4th generation (4G) mobile communications. One of the motivations for this analysis is that the size of the EBG substrate become reasonable for the handset since the frequency used in the 4G mobile communications is 3.5 GHz. Our computational results show that the dipole antenna with EBG structure is found to reduce peak 10-g SAR by 59% as compared with that on a perfect electric conductor.

I. Introduction

Much attention has been paid to the possible health hazard due to electromagnetic (EM) wave exposure from the mobile handsets, because they are used in close proximity to the human head. Safety guidelines for EM wave exposures have been established by international standardization bodies (e.g., [1]). The limit of RF near-field exposure in public environments is 2.0 W/kg for 10 g of tissue. Thus, many studies on specific absorption rate (SAR) compliance have been conducted in the last decade. The realization of low-SAR, high efficiency, and compact antenna becomes essential in the design of a handset antenna. In order to satisfy these requirements at the same time, several structures to reduce SAR have been proposed. Recently, meta-materials, including electromagnetic band-gap (EBG) structures [2, 3, 4], are applied to realize low-SAR antenna [2, 5, 6]. Until now, sufficient attention has not been paid to the SAR reduction for the antenna with an EBG structure, neglecting for a few studies at 2.0 GHz [6].

In the 4th generation (4G) wireless communications system, much attention would be paid to such structures. One of the rationales for this is that the EBG structure is comparable to wavelength and thus become suitable even to the size of mobile handsets at the frequency band assigned for 4G. In the present study, a feasibility of a dipole antenna on electromagnetic band-gap (EBG) substrate was investigated for 4G mobile handsets. It is well known that EBG structures suppress the surface wave on the dielectric substrate [2].

II. Model and Method

A. Antenna with EBG and Model Geometry

A dipole antenna above the perfect electric conductor (PEC) ground plane or the EBG substrate is considered. Fig. 1 illustrates the geometry of the antenna and simplified human head model. The dipole length is 43 mm and its radius is 0.13 mm. The dipole length designed half of the free space wavelength at 3.45 GHz. A mushroom type EBG was considered [2]. This structure introduces an

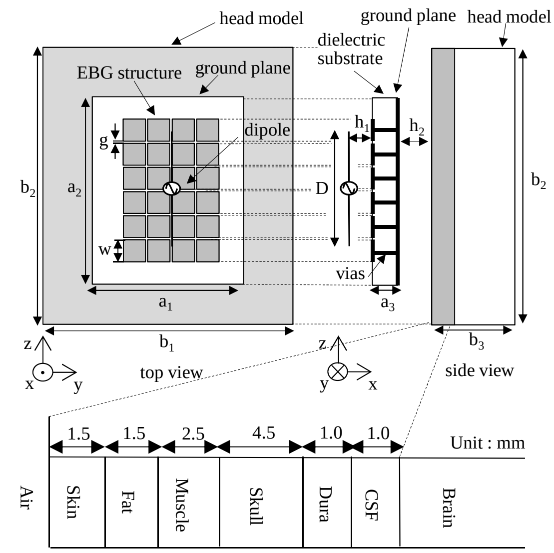

Fig. 1. Geometry of the antenna: a_1 = 50 mm, a_2 = 34 mm, a_3 = 3 mm, D = 43 mm, w = 6 mm, g = 2 mm, b_1 = 200 mm, b_2 = 200 mm, b_3 = 70 mm h_1 = 1.5 mm, h_2 = 10 mm.

inductor L, which results from the current flowing through the vias, and a capacitor C, which is due to the gap effect between adjacent patches. For the structure with patch width W, gap width g, substrate thickness h, and dielectric constant ε_r, the value of inductor L and C can be approximated by the following formulas:

$$L = \mu_0 h \tag{1}$$

$$C = \frac{W\varepsilon_0(1+\varepsilon_r)}{\pi}\cosh^{-1}\left(\frac{2W+g}{g}\right) \tag{2}$$

where μ_0 is the permeability of free apace and ε_0 is the permittivity of free space. From these values, the center frequency of the band gap is approximately given.

The dimensions of the EBG structure are determined as shown in Fig. 1. The dimension of the ground plane is chosen as 34 mm × 50 mm. Total of 24 (4 × 6) elements was located in the proposed structure. The separation between the dipole and the substrate was chosen as 2.0 mm. Thus, the overall height of the dipole antenna from bottom of ground plane of EBG substrate is 4.5 mm. The dipole height of the PEC ground plane is set to 4.5 mm so that two structures have identical overall height. A multi-layer human body model is considered [7]. The separation between the antenna and the head model is 10 mm. The dimension of the head model are 70 mm(x) × 200 mm(y) × 200 mm(z). The model is composed by skin, fat, muscle, skull, dura, CSF, and brain. The electrical constants of tissues are taken form [8].

B. Computational Method

The FDTD method was employed for calculating EM wave propagation. One of the main reasons for using the FDTD method is its stability to finite dielectric structure, as compared with the method of moment. The resolution of the cell is 0.5 mm (*x*) × 1.0 mm (*y*) × 1.0 mm (*z*). The 12-layered PML absorbing boundary was used to terminate the computational region. The output power of the dipole antenna is chosen as 1.0 W. The frequency is 3.45 GHz, which will be assigned to 4G mobile phone communication.

III. Computational Result

We investigate the return loss of a dipole antenna above the PEC ground plane or the EBG structure. The antenna was assumed to be connected with a 50 Ω transmission line. For the antenna with the PEC ground plane, the return loss of dipole was only 3.0 dB. This is because the PEC surface has a 180^{o} reflection phase, so that the reverse image current impedes that an efficient radiation of the dipole, resulting in a very poor return loss. For the antenna with the EBG substrate, the return loss was 11 dB. This improved characteristic is because the EBG structure adjusts the reflection phase in a certain frequency band, so that the dipole antenna can radiate efficiently [2].

In the following discussion, the antenna is assumed to be connected with a matched load in order to clarify the effect of EBG on local SAR properly. Fig. 2 shows the SAR distribution in the head model due to the antenna with the PEC ground plane and EBG substrate. As seen from Fig. 2, the SAR distribution is concentrated behind the PEC ground plane for the antenna with the ground plane. On the contrary, the SAR value becomes higher at the both sides of the substrate. Peak values of averaged SAR over 10 g was 2.64 W/kg for the antenna with PEC while reduced to 1.08 W/kg for the antenna with the EBG substrate. Namely, the SAR for the antenna with the EBG structure was 59% lower than that with the PEC ground plane. The main reason for this reduction would be that the EBG structure suppresses the surface wave, resulting in the suppression of the diffracted wave from ground plane [2]. This tendency was coincident with the finding reported in [6], in which a different structure was considered at 2 GHz band. The radiation efficiency from the antennas was investigated for evaluating antenna performance. The efficiency of the antenna with the PEC ground plane was 90 %, while it was marginally improved to 91 % for the antenna with the EBG substrate.

The effect of antenna separation between the dipole antenna and the ground plane was also investigated. For different separations, the antenna with EBG provided lower SAR and higher efficiency than that with PEC ground plane, suggesting the effectiveness of the structure discussed herein.

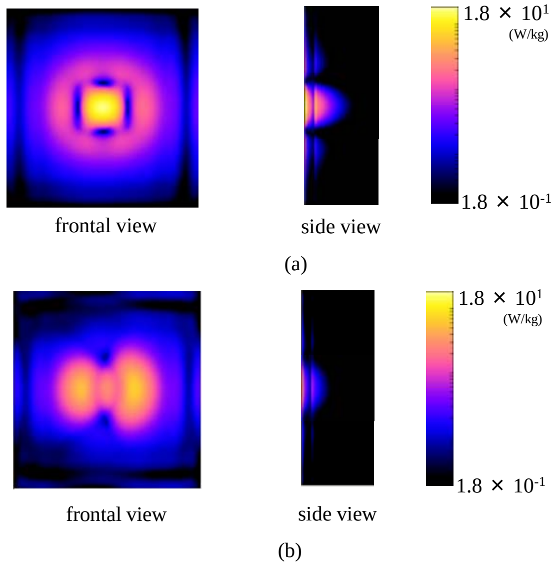

Fig. 2. SAR distribution in the head model due to the antenna on (a) PEC and (b) EBG substrate.

IV. Conclusion

The dipole antenna with the EBG substrate has been investigated at the 3.5 GHz band which will be used for 4G wireless communications system. A multi-layer cubical model was considered as a simplified human head mode. From our computational investigation, the antenna with the EBG structure was found to reduce peak averaged SAR over 10 g by 59 % as compared with that with the PEC ground plane. Thus, the structure discussed herein would be reasonable as a low-SAR, high efficiency, and low-profile design for 4G mobile handset.

V. References

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