SAR Reduction on a Portable Device Using an Intelligent Metamaterial

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1. Introduction

The wireless communication technology has been growing rapidly in the last decade. Because of its convenience, more and more people adopt this technology in cellular phones in the global communication. As the usage of the cellular phone increases, the research on the absorption of electromagnetic energy emitted from the cellular phone has been widely in progress in recent years. The SAR is a defined parameter for evaluating power deposition in human tissue. For the cellular phone, the SAR value must not exceed the exposure guidelines [1, 2].

The SAR value can be evaluated by

$$\mathrm{SAR} = \frac{\sigma |E|^2}{\rho} = c\frac{dT}{dt} \qquad (1)$$

where σ stands for electrical conductivity, ρ for mass density, E for electric field intensity, dT/dt for the time derivative of temperature in body tissue, and c for specific heat. Some numerical results have implied that the peak 1 g average SAR value (SAR1g) may exceed the exposure guidelines when a cellular phone is placed extremely close to the head [3, 4]. Therefore, many researchers are working on reducing the SAR value. In [5], by moving the location of the antenna ground pin or changing the size of ground plane, SAR value can be reduced. In [6], ferrite sheet is placed between the antenna and the human head, resulting in a reduction of the peak SAR value. In [7], SAR is reduced by using EBG (Electromagnetic Band Gap) structure, which is placed between a PIFA antenna and a human head.

In 1968, Veselago [8] explored various electromagnetic properties of the left-handed materials (metamaterials) which did not exist in nature with both negative permeability and permittivity. Shelby et al. combined split-ring resonator (SRR) and thin wire (TW) to realize this artificial structure that had negative refraction index [9]. Metamaterial has many properties, such as negative refractive index, backward wave, inverse Doppler effect and backward Cerenkov radiation. The unique physical properties of metamaterials have greatly aroused researchers' interests recently. In [10], metamaterial is used to reduce the electromagnetic interaction between the antenna and the human head.

This paper proposes an intelligent metamaterial structure to reduce peak SAR value. This intelligent metamaterial can reduce the SAR value when a human head is near around. However, when an antenna with the metamaterial is in free space, the metamaterial does not affect the antenna performance, such as radiation pattern or total radiated power.

2. Design of An Intelligent Metamaterial Structure

The resonant frequency of metamaterial is related to the relative permittivity of the medium. When the metamaterial is close to the phantom, a high relative permittivity material, the resonant frequency of metamaterial will become lower. The proposed metamaterial structure operates at dual bands. The lower band is for working in free space and the higher band is for SAR reduction. When an antenna covered with this intelligent metamaterial is in free space, the metamaterial operates in the lower band and does not affect the antenna performance. When an antenna covered with this intelligent metamaterial is close to a phantom, the metamaterial will work in the higher band. Thus the peak SAR value on the phantom is reduced.

The unit-cell of the intelligent metamaterial structure is shown in Fig. 1, where a=20 mm, b=1 mm, c=1 mm, d=8.5 mm, e=5 mm, f=5.5 mm, g=2.5 mm, s=3 mm, m=1 mm, n=10 mm, and r=8 mm. The substrate is FR4 (εr=4.4), and its thickness is 0.8 mm. Ansoft's High Frequency Simulator (HFSS) is used to calculate the S-parameter of the unit-cell in PEC-PMC waveguide. The method in [11] is used to retrieve constitutive parameters of the semi-infinite periodic slab. Two cases are considered. The first (case 1) has only the intelligent metamaterial unit-cell (Fig. 2(a)), and the second (case 2) has the intelligent metamaterial unit-cell with the phantom shell and the phantom (Fig. 2(b)). Figure 3 shows the S-parameter of the two cases. In case 1, the unit-cell operates in the pass band, which results from the structure in blue color of Fig. 1. In case 2, the unit-cell operates in the stop band, which results from the structure in green color of Fig. 1.

The constitutive parameters of the two cases are shown in Fig. 4. In case 1, the real part of permittivity and permeability are 0.98 and 1.04 at 1.9 GHz, respectively. The refractive index of case 1 equals 1.01. The metamaterial behaves like air. In case 2, the real part of permittivity and permeability are –3.5 and 0.7, respectively. The metamaterial is a single-negative (SNG) material which can block the electromagnetic wave. Therefore, when an antenna of a cellular phone with the intelligent metamaterial is close to the phantom, such as in case 2, the metamaterial can reduce the peak SAR value. When the antenna is far away from the phantom, such as in case 1, the metamaterial will not affect the antenna performance.

3. SAR Reduction by Using Metamaterial

We use SEMCAD to simulate the peak SAR on the phantom and the phantom shell. The simulation setup is shown in Fig. 5. The size of phantom is $156\times156\times226\ mm^3$. The phantom is a lossy material, which has a relative permittivity of 40 and a conductivity of 1.4 S/m. Phantom shell is located outside of the phantom, and the phantom shell has a thickness of 2 mm and a relative permittivity of 3.7. The intelligent metamaterial is composed of six unit-cells, and the size is $60\times40\times0.8\ mm^3$. The distance between the dipole antenna and the phantom shell is 10 mm. The peak SAR1g without metamaterial is 3.61 mW/g. After adding metamaterial between the phantom and the antenna, the peak SAR1g becomes 2.01 mW/g. The peak SAR value has a 44.3% reduction.

4. The Effect on Antenna

Figure 6 shows the return loss of a dipole with and without the metamaterial. The return loss of a dipole with and without the metamaterial at 1.9 GHz are about -13.7 dB and -15.8 dB, respectively. Figure 7 shows the antenna radiation pattern of case 1. As we can see, the radiation patterns with and without the metamaterial are both omnidirectional and the patterns are exactly the same. The TRP is shown in Table I. The metamaterial does not decrease the total radiated power, and it even increases the total radiated power.

5. Conclusions

This paper proposes a novel intelligent metamaterial structure. The metamaterial is suitable for cellular phone applications. When the phone is far away from the human head, the metamaterial behaves like air and it does not affect the antenna performance. When the phone is close to the human head, the metamaterial acts as a SNG material. The peak SAR shows a 44.3% reduction at 1.9 GHz. In the meantime, while the intelligent metamaterial does not affect antenna performance in free space, it even increases the total radiated power. The size of the proposed intelligent metamaterial, which is only $60\times40\times0.8\ mm^3$, is quite compact.

Acknowledgments

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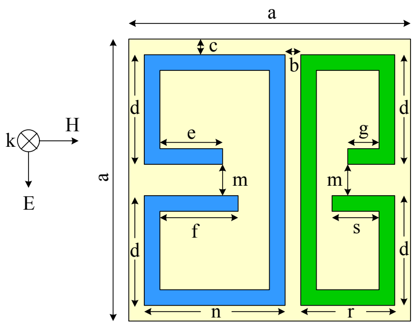

Fig. 1. The unit-cell of intelligent metamaterial structure.

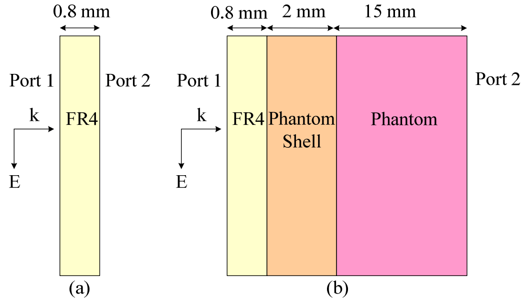

Fig. 2. (a) The lateral view of case 1 (only FR4) (b) The lateral view of case 2 (FR4 with the phantom shell and the phantom).

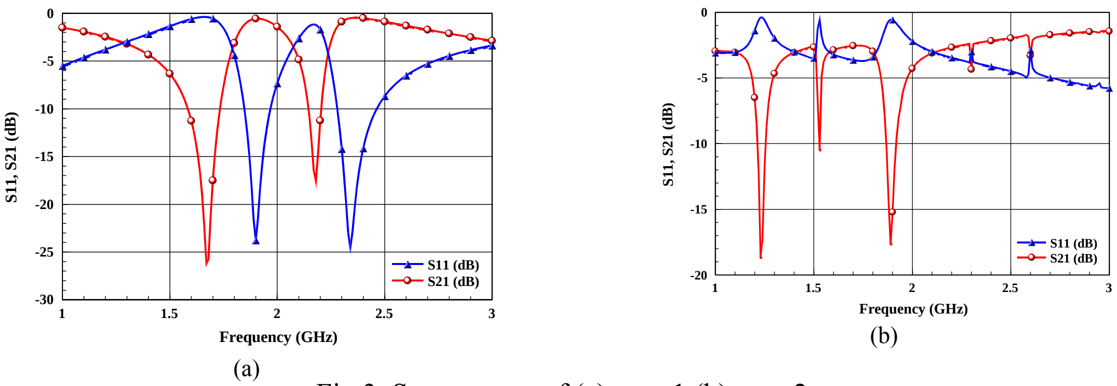

Fig.3. S-parameter of (a) case 1 (b) case 2.

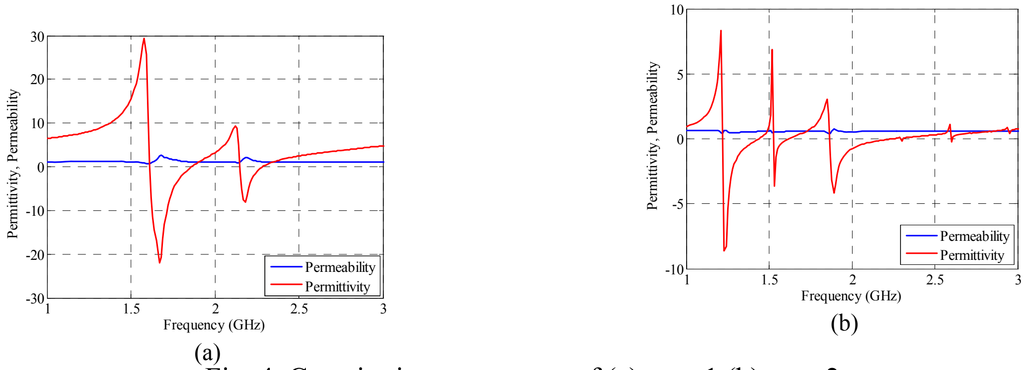

Fig. 4. Constitutive parameters of (a) case 1 (b) case 2.

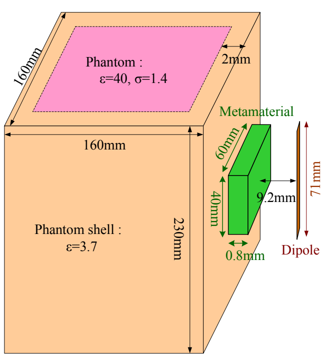

Fig. 5. The setup for SAR simulation.

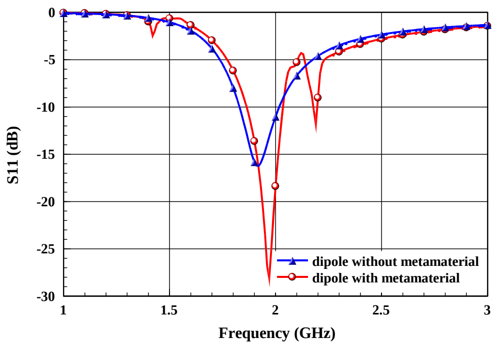

Fig. 6. The return loss of dipole antenna with metamaterial.

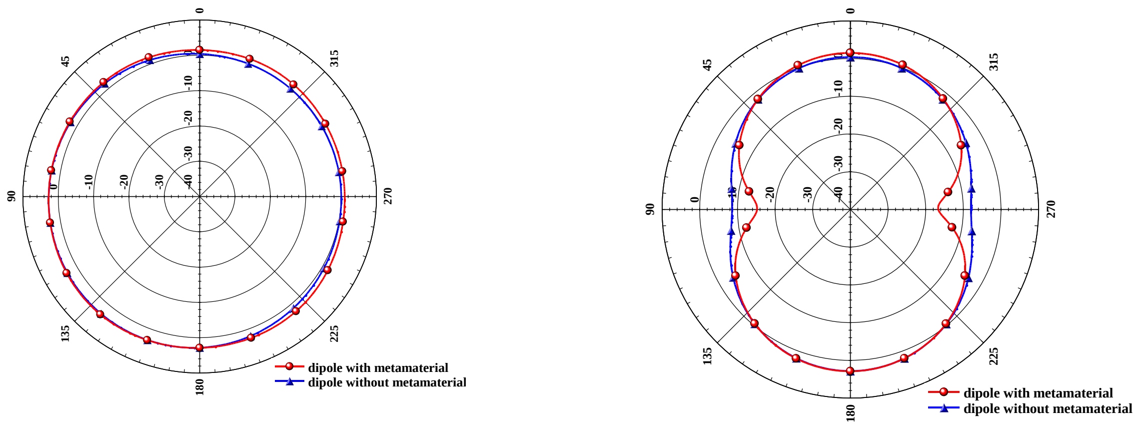

Fig. 7. The radiation pattern of dipole antenna with and without metamaterial on H-plane (up) and E-plane (down).

TABLE I. TOTAL RADIATED POWER

	TRP (W)	TRP (dBm)
Dipole	0.857 W	29.34 dBm
Dipole with Meta	0.979 W	29.91 dBm
Dipole + Phantom	0.291 W	24.64 dBm
Dipole with Meta + Phantom	0.329 W	25.17 dBm

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