Finite Element Analysis of Small Dipole Antenna Surrounded by Negative Epsilon Shell

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Abstract

To miniaturize the antenna, the shape variation and the wavelength shortening methods have been proposed. When the antenna is miniaturized, the antenna characteristics deteriorate. In the input impedance, the resistance value decreases and the reactance value increases. The radiation efficiency decreases, and the bandwidth becomes narrower. Moreover, the matching circuit is required. Even in the case of using the wavelength shortening, the radiation efficiency decreases due to the dielectric or magnetic losses. Recently, Ziolkowski has reported the small dipole antenna with a negative epsilon (ENG) shell structure. This paper presents the finite element analysis of the small dipole antenna with the ENG shell. First of all, the configuration of the ENG shell structure and the relative gain are clarified. The input impedance and the near field distributions are also shown.

Keywords - metamaterial, negative epsilon material, small dipole antenna, finite element method

1 Introduction

To miniaturize the antenna, the shape variation method has been proposed such as the inverted-L, inverted-F, and helical antennas [1-3]. Another realization for miniaturizing the antenna is the wavelength shortening by loading dielectric or magnetic materials.

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Recently, the metamaterial for antenna application has been reported. The negative permittivity or permeability can be obtained by designing the dispersion relation of the unit cell [4]. Ziolkowski has reported the small dipole antenna with a negative epsilon (ENG) shell structure. Very large enhancement of the radiated power was demonstrated analytically. This paper presents the finite element analysis of the small dipole antenna with the ENG shell.

2 ENG Shell Structure

The configuration of the ENG shell structure is shown in Fig. 1. The simulated frequency is 300 MHz (wavelength is 1000 mm). The total length of the small dipole antenna is 10 mm and dipole wire radius is 0.06 mm. The internal and external radiiuses of the shell indicate \( r_1 \) and \( r_2 \), respectively. The input power of 1.0 W with 50\( \Omega \) resistance is excited at centre of the small dipole.

In the simulation model, the relative permittivity \( \varepsilon_r1, \varepsilon_r2 = 1 \) and relative permeability \( \mu_r1, \mu_r2 = 1 \) are set in \( 0 < r < r_1 \) and \( r_1 < r < r_2 \) respectively. Moreover, the ENG material with \( \varepsilon_r2 = -3 \) and \( \mu_r2 = 1 \) is modelled in \( r_1 < r < r_2 \).

Fig. 2 shows the relative gain \( RG \) of the ratio of the radiation power of the small dipole antenna \( P_{\text{dipole}} \) and ENG Shell structure \( P_{\text{ENG}} \), which is defined by

\[
RG = P_{\text{dipole}} / P_{\text{ENG}}
\]

The \( RG = 63 \text{ dB} \) with \( r_2 = 19.09 \text{ mm} \) is confirmed.
3 Electric Characteristics

To achieve the impedance matching, the wire radius of the small dipole changes to 2.5 mm. The input impedance of small dipole antenna without the ENG shell is 0.002−j449.883Ω. The input impedance of the ENG shell is shown in Fig.3. The input impedance becomes 79.4−j1.6Ω with $r_2 = 20.05$ mm at 300 MHz. The $S_{11}$ characteristic of the small dipole antenna with the ENG shell structure is shown in Fig. 4. When $r_2 = 20.05$ mm, the bandwidth become 13 MHz (4.3%). The radiation efficiencies of the small dipole antenna with and without the ENG shell are 63% and 99%, respectively.

4 Near Field Distributions

The near field distributions of the electric and magnetic fields of the ENG shell structure are shown in Figs. 5 and 6, respectively. The electric fields at the upper and bottom parts of the ENG shell become weak due to store the electric charge. This phenomenon is similar to the small normal mode helical antenna. In addition, the strong magnetic fields are distributed on the surface of the ENG shell.

5 Conclusion

The small dipole antenna with the ENG shell structure is simulated by the finite element method. The impedance matching can be achieved easily by adjusting the external shell radius. The real structure of the unit cell should be created for demonstrating experimentally in future.

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References