ANALYSIS OF A MAGNETICALLY-SHIELDED CELLULAR PHONE ANTENNA USING FINITE-DIFFERENCE TIME-DOMAIN METHOD

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Abstract

The characteristics of an antenna used in a transcevier system are studied by several researchers in detail. These characteristics are mainly the radiation pattern, input impedance and the gain of the antenna. This paper proposes a new antenna suitable for cellular phone applications to reduce hazardous electromagnetic radiation toward humans. The antenna is shielded with PEC and shield is coated by a lossy magnetic material. When magnetically shielded antenna is used, it is shown that near electric field toward user drops significantly.

1 Introduction

Recent progress in cellular technology generated a hot spot in antenna research to develop a better antenna to be used in cellular systems. The antenna characteristics such as radiation pattern, gain and input impedance of an antenna are greatly influenced by the existence of humans [1]. It has been showed by Jensen *et al* [2] that the user's head and hand absorbs almost half of the radiated energy. The amount of absorbed energy can be hazardous at high power output levels. Our aim is to block this radiation and allow antenna to radiate its energy on other directions, while we try to maintain antenna performance at its peak. In this paper, a magnetically-shielded antenna is introduced. We choose a simple geometry of a monopole mounted on a ground plane to simply represent the cellular phone antenna. The Finite-Difference Time-Domain (FDTD) method has been chosen as the numerical analysis tool. Due to its flexibility and applicability to non-linear media, FDTD method has gained increasing popularity in recent years. The magnetically shielded case was compared to unshielded case.

2 FDTD Modeling

The FDTD method first introduced by K. S. Yee in 1966 [3] is a numerical technique used in electromagnetic field analysis problems. Because of its *leap-frog* nature, matrix-inversion as in the case of Method of Moments is not required. Maxwell's two curl equations in differential form for isotropic, source free and lossy region are

$$\nabla\times\vec{E} = -\mu\frac{\partial\vec{H}}{\partial t}-\rho\vec{H} \tag{1}$$

$$\nabla\times\vec{H} = \epsilon\frac{\partial\vec{E}}{\partial t}+\sigma\vec{E} \tag{2}$$

The $\rho\vec{H}$ and $\sigma\vec{E}$ terms stand for magnetic and electric losses that may exist inside the medium due to conversion of electromagnetic energy to heat. Here ρ is the magnetic resistivity in Ω/m and σ is the electric conductivity in S/m. In cartesian coordinate system each field component has three sub components and we have the following scalar equations

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y} - \rho H_x) \tag{3}$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z} - \rho H_y) \tag{4}$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu}(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho H_z) \tag{5}$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\epsilon}(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x) \tag{6}$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\epsilon}(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y) \tag{7}$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\epsilon}(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z) \tag{8}$$

Following Yee's central finite-difference scheme and applying proper manipulations, equations (3)-(8) are discretized and finite-difference time-domain update equations are obtained. Initial fields in the computational domain are set to zero. FDTD time-stepping algorithm allows electric fields to be computed from magnetic fields and vice versa. The antenna is centered on a ground plane and is driven by four electric field components to simulate coaxial feed connection [4]. Excitation source is chosen to be a Rayleigh pulse and is expressed as

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$$V(t) = A_0 e^{-\alpha(t-\beta\Delta t)^2}\sqrt{\alpha}(t-\beta\Delta t) \qquad (9)$$

Here β determines the pulse width and $\alpha = (\frac{4}{\beta\Delta t})^2$ adjusts the pulse amplitude at truncation. Following cases are considered

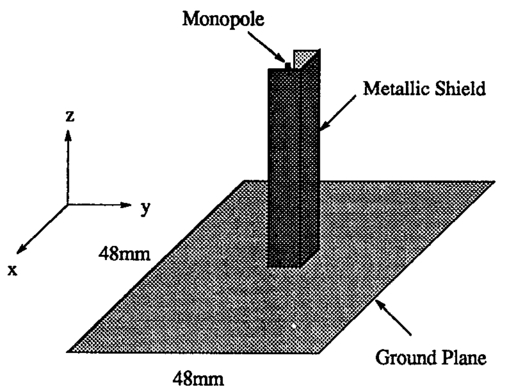

Figure 1: Shielded Monopole

- Monopole on a ground plane
- Shielded-monopole on a ground plane
- Magnetically-shielded monopole on a ground plane

Ground plane dimensions are chosen to be 48 mm×48 mm. Fig. 1 shows the geometry of the problem. Operation frequency is 1.8 GHz and antenna is $\lambda/4$ at this frequency. A shield has been implemented simply with three PEC walls rising in z-direction as shown in Fig. 1. Shield dimensions are 8 mm in y-direction and 16 mm in x-direction. Fig. 2 shows the cross section of the shield with magnetic material coating. In all numerical simulations cubical Yee cells are used. For the first two cases cell size is chosen to be 2 mm in order to characterize EM interaction accurately inside the shield. Therefore we are able to put four cells between the monopole and the PEC shield. With this cell size input impedance of the antenna can be observed accurately till 15 GHz when FDTD problem space contains only free-space and PEC. This is due to numerical dispersion constraints. For the magnetically shielded case the constitutive parameters of the medium are set to $\epsilon_r = 10$ and $\mu_r = 10 - j2$. The imaginary part of μ_r is taken into account as a magnetic resistivity of $\rho = 28425$ at 1.8 GHz. Cell size for this case is 1.333 mm and cell resolution at 2 GHz corresponds to $11.25\Delta u$ where Δu is the cubical cell size. Parameter β of Rayleigh pulse is set to 232 for the magnetically shielded monopole case and 128 otherwise. Time step size is determined from Courant Stability Condition. PML absorbing boundaries have been used with a reflection coefficient of $R(0) = 10^{-5}$ and a PML thickness of 8 cells.

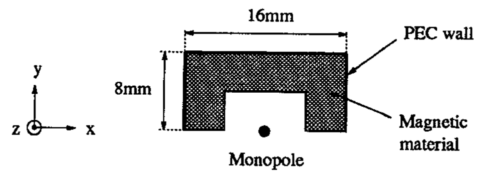

Figure 2: Magnetically shielded monopole

PML ABC is introduced by Berenger [5] and extended and validated by [6] , recently. PML works on the basis of a lossy non-physical media that surrounds the FDTD problem space. The wave propagating in normal direction to PML media will be attenuated so rapidly that exponential updating coefficients are used inside the PML medium. While wave is traveling thru the PML region, the impedance of medium is set to vacuum impedance of 377 Ω. Therefore, reflections due to impedance mismatch are avoided.

3 Results

Fig. 3 shows the magnitude of electric field along y-direction. Antenna is excited with a sinusoidal source at 1.8 GHz. Once the fields achieved steady-state, magnitudes of electric field components have been picked up by simply observing the slope variation of the steady-state data. In Fig. 3 antenna is located at zero reference point. Field distribution is plotted from -40 mm to +38 mm. The x-axis represents the distance away from the antenna. Each case is normalized with respect to its own maxima. Electric field distribution for no shield case is symmetric as expected. PEC shield is located 8 mm away from the antenna and field magnitude exhibits a sharp drop at shield location. It is clear that PEC and magnetic shield reduce the EM radiation in one direction which can be the user direction.

Input impedance of the monopole was compared for the above cases, as shown in Fig. 4 and Fig. 5. Rayleigh pulse is used as excitation source to obtain broadband frequency domain impedance results. Impedance data is obtained using time-domain transient current and voltage at antenna input terminals. Applying Fast Fourier Transform and dividing voltage by current at each frequency point yields the desired input impedance of the antenna. While antenna is shielded, real part of the input impedance almost drops to zero. This phenomenon occurs due to the excessive loading of the antenna by the PEC shield and makes matching very difficult. Using magnetic shielding increases the real part of the input impedance. Therefore antenna can be well matched to a transmission line around 1.8 GHz. Fig. 5 shows the imaginary part of the input impedance for the above cases.

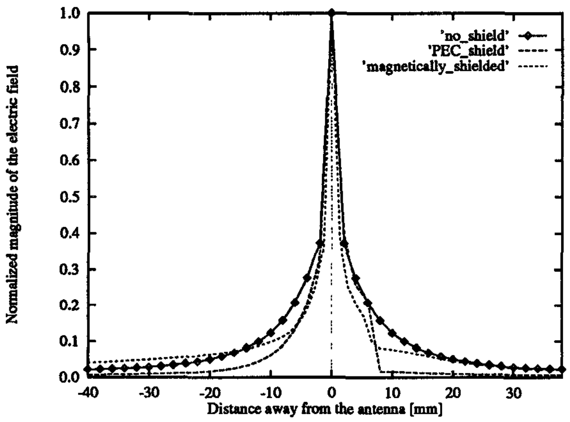

Figure 3: Electric field distribution along y-direction

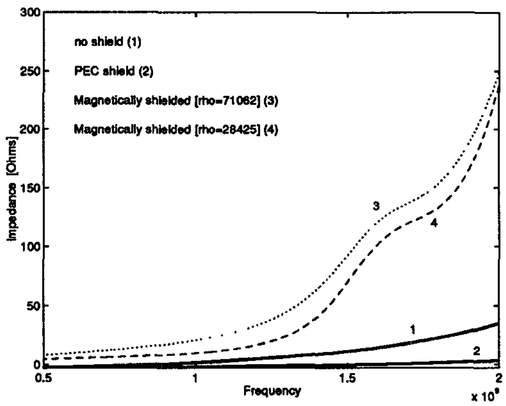

Figure 4: Real input impedance of the antenna

Radiation patterns of above cases are also investigated. Radiation pattern calculations are performed using a sinusoidal source at 1.8 GHz. FDTD problem space is enclosed by an inner virtual surface a couple of cells away from the absorbing boundaries. After steady-state, phase and amplitude information of the fields on the virtual surface are found via discrete fourier transform. A near-to-far zone transformation based on field equivalence theorem completes the cycle. Refer to Fig. 6 for E plane ($\theta = 90°$) far-zone radiation patterns. There is a reduction in far-field in the direction of the user for both PEC and magnetic shield. magnetic shield.

4 Conclusion

When PEC shield is used, input resistance drops to zero level. It is clear that matching will be extremely difficult for this situation. Near field patterns show that when no absorber is used (PEC shield case) radiation toward human is greatly reduced. However, magnetic shielding

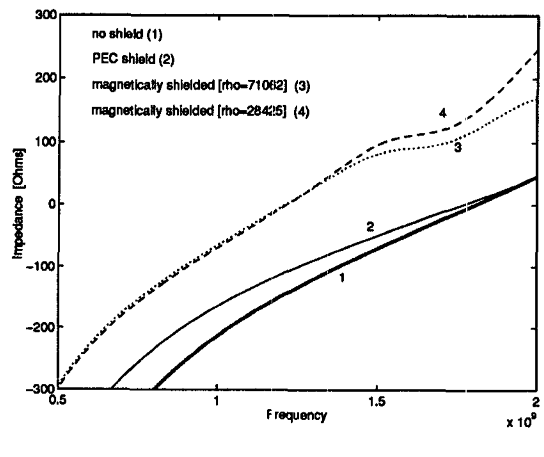

Figure 5: Imaginary input impedance of the antenna

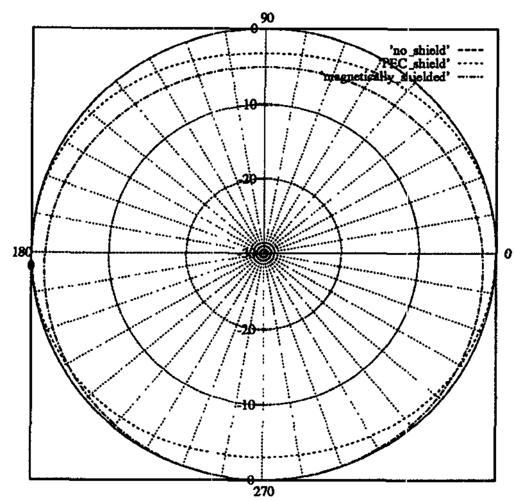

Figure 6: Radiation patterns

performs better than PEC shielding. Antenna measurements as well as measurements of material parameters at 880 MHz are still in progress. It can be concluded that radiation toward human can be reduced using a magnetically shielded antenna without sacrificing the radiation characteristics of the antenna.

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