A Numerical Analysis of Induced Current in Human Standing Over Low-Loss Ground Plane by FDTD Method

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1. Introduction

In recent year, information-based society grows rapidly more and more and we have been using wireless communication in various fields. The wireless communication is essential to our social activity, e.g., broadcasting. The mobile communications often operated from medium frequency to ultra high frequency bands. On the other hand, there is a possibility that human beings may be scared with harmful effects of electromagnetic wave. For avoiding potential harms of electromagnetic wave, we need further studies on health effects of electromagnetic field. In the case of the far-field exposure in Very High Frequency (VHF) band, it is reported that the whole-body resonance could occur. At the whole-body resonance, intensive induced current could be maximum value. The RF safety guidelines, therefore recommend the most strict exposure limits in VHF band[1]. On the other hand, a study on electromagnetic wave exposure affect for infants have been performed widely. Because, the opportunity of electromagnetic wave exposure is a lot and the period of exposure can be long-term.

In this study, we consider an efficient analyzing method for the numerical analysis of induced current in human standing over low-loss ground plane. The Green function for the problem was obtained[2], therefore, the Method of Moment (MOM) can be used for solving this problem. However, the Sommerfeld integral is included in this calculation, the Sommerfeld integral is very difficult to converge, so, it is very difficult to analyze the problem by using the MoM. The FDTD method is widely used to analyze a human body model, because, the numerical human data including the electric property of tissue is provided as the Voxel model[3], the Voxel data can be included to FDTD analysis easily[4]. In this paper, we use the FDTD method. Fig.1 shows the scatterer as a human on the semi-infinite plane and the FDTD analysis model. In the FDTD analysis, a special boundary is needed to truncate the analysis at the end of computation space. In order to realize semi-infinite ground plane, the PML absorbing boundary which matched with lossy ground is used[6]. However, the PML which matched with lossy ground is needed huge computation resources by comparison with the PML for free space. Furthermore, the PML which matched with lossy ground is very complicated, so, the coding is very difficult. In this paper, we will propose an efficient modeling method to model semi-infinite ground plane. The method uses surface

Figure 1: Lossy material on ground

Figure 2: Lossy material on ground
Impedance boundary condition (SIBC). And we calculate induced current of lossy square rod by using proposed method. The effectiveness of the proposed method is confirmed by numerically.

2. The Modeling Method of Semi-infinite Ground in the FDTD Method

Fig.1 shows the analysis model. In this model, the scatterer is placed over the lossy ground plane. The complex permittivity of the ground is expressed as \( \varepsilon(\omega) = \varepsilon_0 \varepsilon_s + \sigma_s/\omega \), where \( \varepsilon_s, \sigma_s \) are relative permittivity of ground and conductivity respectively. In order to realize semi-infinite ground plane, the analysis region must be surrounded by matched PML as Fig.2[5]. However, the special treatment is needed to match with lossy medium. In order to match the PML absorbing condition with lossy material, the complex permittivity of PML should be

\[
\varepsilon_{\text{PML}}(\omega) = \varepsilon_0 \varepsilon_s + \sigma_s/\omega + b_0 (j\omega)^2
\]

where \( b_0 = \frac{\sigma_s c}{\mu_0} = \frac{\sigma_s c}{\varepsilon_0} \). From eq.(1), the PML becomes a dispersive material. In the FDTD method, some special techniques are needed to analyze dispersive material such as Recursive Convolution (RC) method[7]. The RC method requires extra computational resources by comparison with original FDTD method. Furthermore, the coding of RC method is relatively complicated. Next, we will propose an efficient modeling method of semi-infinite ground plane by using SIBC in FDTD method. The derivation of SIBC for low-loss material and its calculating method will be indicated. A derivation of SIBC for high-loss material has been indicated. The surface impedance of material whose electric property  permittivity \( \varepsilon_s \), conductivity \( \sigma_s \), permeability \( \mu_s \) is obtained as

\[
Z_s(\omega) = \sqrt{\frac{j\omega \mu_0}{\varepsilon_s + j\omega \varepsilon_s}}
\]

but, it is very difficult to include FDTD method by using eq.(2). On the other hand, the electric property of ground is low-loss and high permittivity at VHF bands, therefore, the surface impedance can be approximated as

\[
Z_s(\omega) = \sqrt{\frac{\mu/\varepsilon_s}{1 + \sigma_s/j\omega \varepsilon_s}} \approx Z \left( \frac{1}{1 + \sigma_s/j\omega \varepsilon_s} \right)
\]

where \( Z = \sqrt{\mu_0/\varepsilon_s} \). The tangential component of electric field at the ground surface can be expressed by using surface impedance. Therefore the computation resources can be reduced by using the surface impedance, because, the calculation electric filed which is inside of ground becomes unnecessary. Next, we will indicate briefly how to formulate obtained surface impedance into the FDTD method. The FDTD geometry is shown as Figure 3. The electric field on the SIBC is calculated by using surface impedance as

\[
E_x(t) = \int_0^\infty Z_s(\tau) H_y(t - \tau) d\tau
\]
Descritizing eq.(4) and using FDTD notation, the update equation of FDTD method is expressed as

\[
H_y^{n+\frac{1}{2}}(i + \frac{1}{2}, j, k + \frac{1}{2}) = \frac{1}{\Delta t} \left\{ \frac{\mu}{\Delta t + Z\chi_0} \left( i + \frac{1}{2}, j, k + \frac{1}{2} \right) \right. \\
- \frac{1}{\Delta z} \left( E_x^n(i + \frac{1}{2}, j, k) - \Phi^n \right) + \frac{1}{\Delta z} \left( E_x^n(i + 1, j, k + \frac{1}{2}) - E_x^n(i, j, k + \frac{1}{2}) \right) \}
\]

(5)

where \( \chi_0 = -\frac{\mu}{\Delta t} \int_0^{\Delta t} e^{-\frac{\sigma_s}{2} t_\lambda} dt \), \( \Phi^{n-1} = -\frac{\mu}{\Delta t} H_y^{n-1} \int_{\Delta t}^{2\Delta t} e^{-\frac{\sigma_s}{2} t_\lambda} dt \). We can derive another component. No calculation is necessary in ground plane using this equation.

3. Results

In order to confirm the validity and effectiveness of our proposed method, we calculate the induced current of PEC wire over ground plane by FDTD method in which uses PML for modeling semi-infinite ground plane, proposed method amd the MoM. In the MoM analysis, the Sommerfeld integral is included in impedance matrix. In this calculation, integration is perfomed by substitution as

\[
\int_0^{\infty} d\lambda = \int_0^{k_0} d\lambda + \int_{k_0}^{k_0n_1} d\lambda + \int_{k_0n_1}^{\infty} d\lambda
\]

(6)

Then we can take a brunch cut and infinite integral is replaced as finite integral. Where \( \epsilon_1 \) is complex permittivity of ground then \( n_1 = \text{Re}(\sqrt{\epsilon_1}) \). In addition, There are a lot of estimation method of Sommerfeld for example, Exterpolation Method. However, in this paper, we can obtaine good result by using eq.(6).

The calculated induced current is shown in Fig.4. The radius of the wie is 2.35cm, the length of the wire is 175cm. The wire is set 17.5cm away from semi-infinite ground. The imputed pulse is plane wave and frequency is 79.4MHz. The ground is semi-dry condition. The accuracy is cofirmed by comparison with MoM. The proposed method is good agreement with MoM result. In MoM calculation, the number of segment was 10. Next, the computer resources are compared. The computer resources are indicated in Table.1. Therfore, the proposed method is very effective to model semi-infinite ground.

Next, the induced current of lussy rod is calculated. The numerical model is shown in Fig.5. The electric property of the lossy rod is set as homogeneous model. the electric property of infant is used as 2/3 musle[6]. Calculated induced curent is shown in Fig.6.

Figure 4: PEC wire over semi-infinite ground

Figure 5: Calculated normalized induced current
4. Conclusion

In this paper, we proposed efficient modeling method for semi-infinite ground plane. From results, the proposed method was good agreement with PML method and MoM. Therefore, the proposed method is very effective by comparison with using PML method.

References


