FDTD Analysis of Induced Current of PEC Wire Which In Contact with Half Space Lossy Ground by Using Surface Impedance Boundary Condition

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***Abstract*— In recent years, electromagnetic waves are widely used. On the other hand, a fraction of electromagnetic waves are absorbed into the human body. In the case of far filed exposure, whole body resonance phenomena are observed at VHF frequency band when the component of E-field is parallel to the human body's height. In this phenomenon intensive induced current is observed in the human body. The induced current maybe depends on earth condition. In this paper, in order to estimate an effect of lossy flat earth for induced current, the induced current of object which is in contact with earth is analyzed by the FDTD method. The flat earth is modeld by using surface impedance boundary conditions to reduce calculation resources.**

I. Introduction

In recent years, electromagnetic waves are widely used. On the other hand, a fraction of electromagnetic waves are absorbed into the human body. In the case of far filed exposure, whole body resonance phenomena are observed at VHF [1] frequency band when the component of E-field is parallel to the human body's height as shown in Fig.1. In this phenomenon intensive induced current is observed in the human body. The induced current maybe depends on earth condition. In international guidelines, the limitations of the exposures are provided [2]. In order to analyze this phenomenon, an FDTD method[3] is widely used, because, the numerical human data including the electric property of tissue is provided as the Voxel model, the Voxel data can be included to FDTD analysis easily.

In the FDTD analysis, Perfect Matching Layer absorbing boundary conditions (PML) is effective to model half space flat earth. However, PML is required relatively large computation resources. Furthermore, electric property of earth is a lossy media. An implementation of the PML for lossy media is complicated, because the PML for lossy media should be implemented as dispersive materials.

On the other hand, in [4], our group has proposed efficient modeling method to model half space flat earth by using Surface Impedance Boundary Condition (SIBC).

In this paper, in order to estimate an effect of lossy flat earth for induced current, the induced current of object which is in contact with earth is analyzed by the FDTD method. The flat earth is modeld by using SIBC. In this paper, the PEC wire is used instead of human body. The effectiveness of the method is confirmed by comparing with PML modeling method.

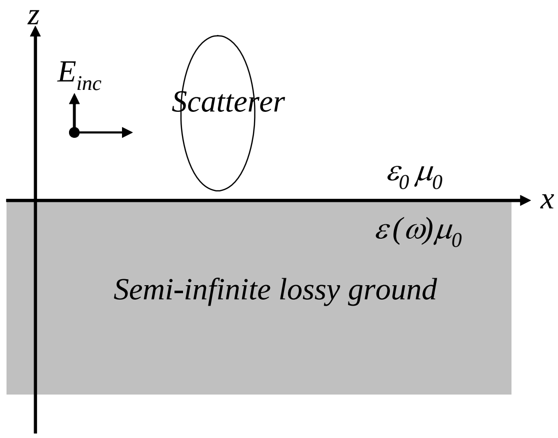

Fig.1 Scatterer over the semi-infinite ground

II. The modeling method of half space lossy flat earth in the FDTD method by using SIBC

In this section, an implementation method of SIBC to model half space lossy flat earth into FDTD calculation and its estimation method are explained briefly. A derivation of SIBC for high-loss material has been indicated in [5]. The surface impedance of material whose electric property permittivity σ_s conductivity σ_s permeability ε_0 is obtained as

$$Z_s(\omega) = \sqrt{\frac{j\omega\mu_0}{\sigma_s + j\omega\varepsilon_s}} \qquad (1)$$

The purpose of this paper to introduce SIBC of lossy soil that instead of real lossy flat earth. The FDTD method is time domain analysis method. Unfortunately, time domain expression of eq.1 may include Bessel functions. The Bessel functions are not easy to introduce the FDTD method, because special treatment is required.

On the other hand, electric properties of soil in VHF frequency band are indicated in table.1

Table 1: electric property of soil

Frequency[MHz]	σ [S/m]	εr
19.9	0.001	15.0
31.6	0.001	15.0
39.8	0.00105	15.0
50.1	0.0011	15.0
63.0	0.0012	15.0
79.4	0.0016	15.0

From Table.1, the surface impedance can be approximated by using binomial approximation as

$$Z_s(\omega) = \sqrt{\frac{\mu/\varepsilon_s}{1+\frac{\sigma_s}{j\omega\varepsilon_s}}} \simeq Z\left(\frac{1}{1+\frac{\sigma_s/2}{j\omega\varepsilon_s}}\right) \qquad (2)$$

where $Z = (\mu_0/\ \varepsilon_s)^{1/2}$. Eq.(2) can be transform easily to time domain. The time domain expression is simple expression, so eq.(2) is useful for the FDTD calculation. The tangential component of electric field at the flat earth surface can be expressed by using surface impedance and magnetic field. Therefore the computation resources can be reduced by using the surface impedance, because, the electric and magnetic field which is inside of lossy flat earth electric filed is unnecessary.

Next, we will explain briefly how to formulate the obtained surface impedance into the FDTD method. The FDTD geometry is shown in Fig.2. The electric field on the SIBC is calculated by using surface impedance. Next, we will indicate briefly how to formulate obtained surface impedance into the FDTD method. The FDTD geometry is shown in Fig.3. The electric field on the SIBC is calculated by using surface impedance as

$$E_x(t) = \int_0^t Z_s(\tau) H_y(t-\tau)d\tau \qquad (3)$$

Descritizing eq.(3) and using the FDTD notation, $H_y^{n+\frac{1}{2}}$ is expressed as

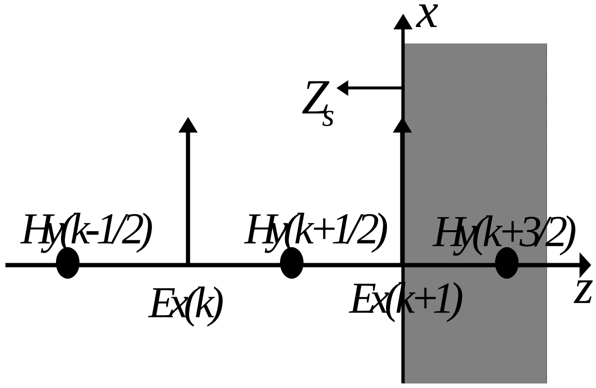

Fig.2 FDTD cell model

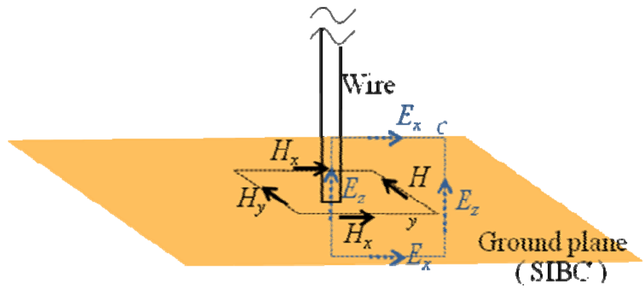

Fig.3 SIBC modeling

$$H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) = \frac{1}{\frac{\mu}{\Delta t}+\frac{Z+\chi^0}{\Delta z}}$$
$$\left\{\frac{\mu}{\Delta t}H_y^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)\right.$$
$$-\frac{1}{\Delta z}\left(E_x^n\left(i+\frac{1}{2},j,k\right)-\Phi^n\right)$$
$$\left.+\frac{1}{\Delta x}\left\{E_y^n\left(i+1,j,k+\frac{1}{2}\right)-E_y^n\left(i,j,k+\frac{1}{2}\right)\right\}\right\} \qquad (4)$$

where

$$\chi^0 = -\frac{\sigma_s}{2\varepsilon_s}\int_0^{\Delta t} e^{-\frac{\sigma_s}{2\varepsilon_s}t}dt$$

$$\Phi^{n-1} = -\frac{\sigma_s}{2\varepsilon_s}H_y^{n-\frac{1}{2}}\int_{\Delta t}^{2\Delta t} e^{-\frac{\sigma_s}{2\varepsilon_s}t}dt \quad - \quad e^{-\frac{\sigma_s}{2\varepsilon_s}\Delta t}\Phi^{n-2}$$

respectively.

Next, we expand SIBC for PEC wire in contact with half space ground. Fig. 3 shows FDTD cell on the ground plane. In this figure H_y and H_x are obtained by using SIBC as eq.(4). In order to model PEC wire which in contact with lossy flat earth, E_z component which just under the wire should be E_z=0. However, the calculated induced current is not good agreement with a PML result. The PML result is using few cells thickness soil and calculation reason of soil area is truncated by the PML which is matched with lossy soil. In this case, the PML is dispersive material. Therefore, the implementation of this PML is relatively complicated.

Next, we will explain treatment method for in contact with SIBC cells. A special treatment is needed to obtain H_y and H_x vicinity of the wire. The integral form of Faraday's law is effective to model this special condition. Applying Faraday's law to contour C in Fig.3, the update equation of H_y can be obtained as

$$H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)=\frac{2}{\frac{\mu}{\Delta t}+\frac{Z+\chi^0}{\Delta z}}$$
$$\left\{\frac{\mu}{\Delta t}H_y^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)\right.$$
$$-\frac{1}{\Delta z}\left(E_x^n\left(i+\frac{1}{2},j,k\right)-\Phi^n\right)$$
$$+\frac{1}{\Delta x}\left\{0.5E_z^n\left(i+1,j,k+\frac{1}{2}\right)\right.$$
$$\left.\left.-E_z^n\left(i,j,k+\frac{1}{2}\right)\right\}\right\} \quad (5)$$

III. IMPROVING CALCULATION ACCURACY

In this section, improving calculation accuracy technique is proposed. In order to improve the calculation accuracy, we introduce quasi-static approximation[6]. In the original FDTD method, the electric field distribution is assumed as constant. This may be on reason of accuracy deterioration. Static fields are dominat near the antenna. Fig.4 shows analysis model to obtain static field distribution near the antenna on the flat earth. In this model, the antenna is uniformly charged. The electro static potential $\phi(\rho,z)$ is obtained as

$$\phi(\rho,z)=\frac{\sigma}{4\pi\varepsilon}\left\{\frac{\log\left|z+\sqrt{z^2+\rho^2}\right|}{\log\left|z-l+\sqrt{(z-l)^2+\rho^2}\right|}+R\frac{\log\left|z+l+\sqrt{(z+l)^2+\rho^2}\right|}{\log\left|z+\sqrt{(z)^2+\rho^2}\right|}\right\}$$

Where.

$$R=(1-\varepsilon_r)/(1+\varepsilon_r)$$

The obtained electric field can be included into FDTD method by using integral form of Faraday's law[6].

IV. RESULTS

In order to confirm the effectiveness of this paper method, induced current by plane wave incident is calculated. The calculated induced current in PEC wire which in contact with lossy flat earth plane is shown in Fig. 5. The length of PEC wire is 175cm. The imputed pulse is plane wave and frequency is 79.4MHz. The ground is semi-dry condition, the electric properties are ε_s=15.0 σ_s=0.0016. In Fig.5, solid line is calculated by using exact ground plane modeling which uses few cells thickness soil and calculation reason of soil area is truncated by the PML which is matched with lossy soil. The calculated induced current is good agreement with PML result. Therefore the proposed method is effective to model PEC wire which touched semi-infinite ground plane.

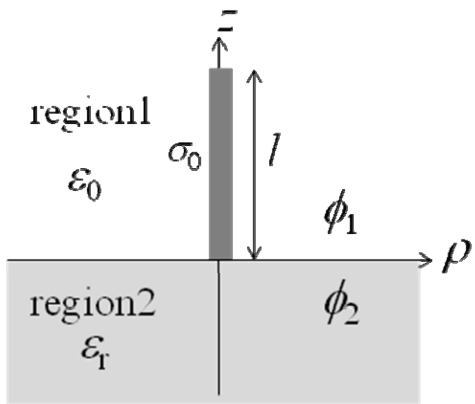

Fig.4 SIBC modeling

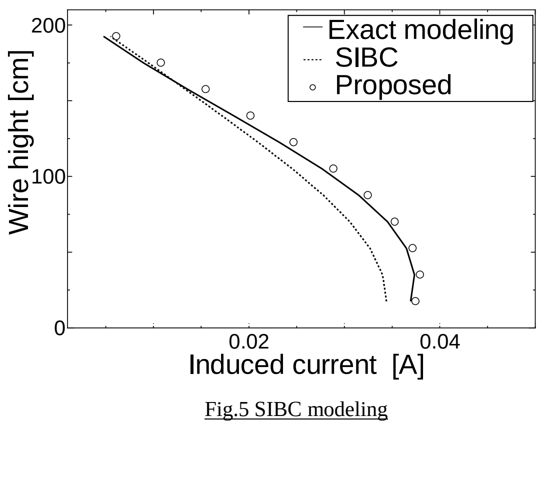

Fig.5 SIBC modeling

V. CONCLUSION

In this paper, the induced current in PEC wire which in contact with lossy flat earth plane was calculated. In the calculation, SIBC was used to model lossy flat earth plane The result is good agreement with PML result. Therefore the proposed method is effective to model PEC wire which in contact with lossy flat earth plane.

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