FDTD Analysis of Dipole Antenna in Anisotropic Plasma

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1. Introduction

The characteristics of antennas immersed in plasma medium is important for many research areas such as the space science and the plasma process. A large number of theoretical researches have been reported so far using the cold plasma theory and exact or quasi-static Green's function [1]-[3]. In the past several years, the FDTD method has been widely used for the analysis of electromagnetic analysis for not only usual isotropic medium but also dispersive or anisotropic medium because of its flexibility and effectiveness. However, the absorbing boundary condition (ABC) applicable to both dispersive and anisotropic medium, which is necessary for the numerical analysis of antennas in the infinite plasma medium, has not yet been reported. Recently, a PML-based absorbing boundary condition applicable to the dispersive or anisotropic medium [4], [5]. In this report, a dipole antenna located in the magnetoplasma by using the proposed absorbing boundary condition. The plasma medium is approximated by a uniaxially anisotropic medium. The numerical results are compared to experimental data [6] and numerical results by using the method of moment with exact Green's function.

2. Formulation of FDTD

The model for calculation is shown in Fig.1. A dipole antenna with length $2l$ parallel to z axis is located at the center of the analysis region. The analysis region is occupied by a uniform anisotropic plasma and is surrounded by dispersive and anisotropic PML absorbing boundary. The static magnetic field is applied parallell or perpendicular to the dipole antenna. The Maxwell's equation is given by

$$\nabla \times \boldsymbol{E} = -\mu_0 \frac{\partial \boldsymbol{H}}{\partial t} \tag{1}$$

$$\nabla \times \boldsymbol{H} = \frac{\partial \boldsymbol{D}}{\partial t} \tag{2}$$

$$\boldsymbol{D} = \varepsilon_0 \overline{\varepsilon}(\omega) \cdot \boldsymbol{E} \tag{3}$$

where $\overline{\varepsilon}$ is the relative tensor permittivity. Using the uniaxually anisotropic approximation, the relative tensor permittivity is given by

$$\overline{\varepsilon}(\omega) = \begin{pmatrix} \varepsilon_{xx}(\omega) & 0 & 0 \\ 0 & \varepsilon_{yy}(\omega) & 0 \\ 0 & 0 & \varepsilon_{zz}(\omega) \end{pmatrix} \tag{4}$$

where components of tensor are

$$\varepsilon_{xx}(\omega) = \varepsilon_{yy}(\omega) = 1 - \frac{XU}{U^2 - Y^2}, \quad \varepsilon_{zz}(\omega) = 1 - \frac{X}{U} \tag{5}$$

$$X = \frac{\omega_p^2}{\omega^2}, \quad Y = \frac{\omega_H}{\omega}, \quad U = 1 - j\frac{\nu}{\omega} \tag{6}$$

Table 1: Plasma parameters

$Parameter$	$slant\,angle[deg.]$	$f_p[MHz]$	$f_H[MHz]$	$f_u[MHz]$	$\nu[Ms^{-1}]$
1	0	228	203	308	70
2	90	140	207	250	70

and ω_H, ω_p, ν are angular electron cyclotron frequency, angular electron plasma frequency, and collision frequency, respectively. $\varepsilon_{xx} = \varepsilon_{yy}$, and ε_{zz} have Lorentz type and Drude type dispersion, respectively. The leap frog calculation is carried out as $\boldsymbol{E} \Rightarrow \boldsymbol{H} \Rightarrow \boldsymbol{D} \Rightarrow (\boldsymbol{E})$ in turn. Discretization for $\boldsymbol{E} \Rightarrow \boldsymbol{H}$, $\boldsymbol{H} \Rightarrow \boldsymbol{D}$ are the same to the normal FDTD calculation. For $\boldsymbol{D} \Rightarrow (\boldsymbol{E})$ procedure, Eq.(3) has to be transformed into time domain by using the Fourier transform since the medium is strongly dispersive. In order to analyze such a dispersive medium, the ADE method is applied since the dispersive and anisotropic PML can be applied easily. Time domain representation for $D_x = \varepsilon_x E_x$, $D_z = \varepsilon_z E_z$ is given by

$$\left[\frac{\partial^3}{\partial t^3} + 2\nu\frac{\partial^2}{\partial t^2} + (\nu^2 + \omega_H^2)\frac{\partial}{\partial t}\right] D_x = \varepsilon_0 \left[\frac{\partial^3}{\partial t^3} + 2\nu\frac{\partial^2}{\partial t^2} + (\nu^2 + \omega_H^2 + \omega_p^2)\frac{\partial}{\partial t} + \omega_p^2 \nu\right] E_x \tag{7}$$

$$\left[\frac{\partial^2}{\partial t^2} + \nu\frac{\partial}{\partial t}\right] D_z = \varepsilon_0 \left[\frac{\partial^2}{\partial t^2} + \nu\frac{\partial}{\partial t} + \omega_p^2\right] E_z \tag{8}$$

and equation for E_y is similar to eq.(7). Discretization of eqs.(7) and (8) is rather complicated and is omitted here.

Plasma parameters used here are the same to the case of [6] and shown in Table 1. For parameter 1 and 2, the dipole antenna is located parallel and perpendicular to the static magnetic field, respectively. The electron cycrotron frequency and collision frequency are the same, but the electron plasma frequency is different. The radius of the antenna is 1mm.

3. Numerical results

Fig.1 shows the model for the calculation, where a dipole antenna generating E_z is located at the center of analysis region, and the exciting pulse is $p(t) = cos^6(\frac{\pi t}{\Delta})$ and $\Delta = 0.5ns$. The cell size is 5.45cm, number of cells are $71 \times 71 \times 71$, and the time step Δt is 15ps. The PML thickness is 10 cells.

Time response of the voltage and the current at the feed point for parameter 1 are shown in Fig 2. Since the voltage and the current attenuates and converges at about 75ns (5000 step), maximum time step of 5000 is used.

The input impedance of the dipole antenna in the case of the static magnetic field parallel to the dipole antenna is shown in Fig.3 (Parameter 1). Weak resonance near the electron plasma frequency can be observed, but dominant resonance has observed at the upper hybrid resonance frequency. Agreement between the FDTD results and the experimental data is considered to be satisfactory. The FDTD results are also compared to numerical results by using the method of moment with the exact Green's function. Agreement between the FDTD results and the MoM results is fairly good rather than the comparison with experimental data. At the high frequency region, MoM results slightly agrees with the experiment rather than FDTD.

The input impedance of dipole antenna in the case the static magnetic field perpendicular to the antenna is shown in Fig.4 (Parameter 2). Agreement between the FDTD results and the experimental data is again satisfactory. Similar to Fig.3, the FDTD results again well with the MoM results.

4. Conclusion

Characteristics of a dipole antenna located in a magnetoplasma have been analyzed by using proposed dispersive and anisotropic PML absorbing boundary condition. Numerical results of the input impedance calculated by the FDTD have been shown and compared with the experimental data and the results of the MoM confirming the applicability and the effectiveness of the FDTD for the antenna analysis in magnetoplasma.

References

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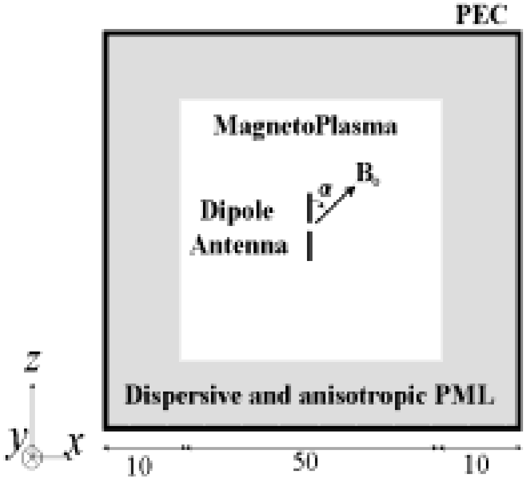

Figure 1: Model for calculation.

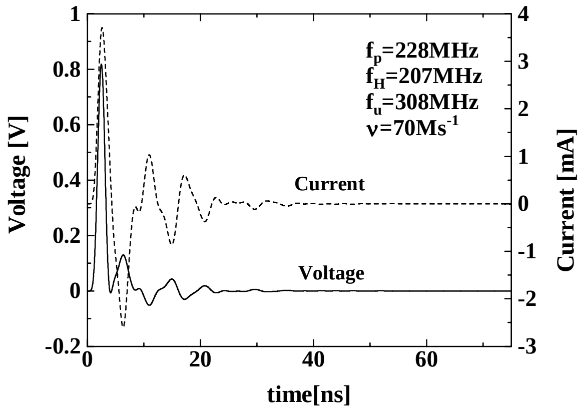

Figure 2: Time responce of voltage and current at the feed point.

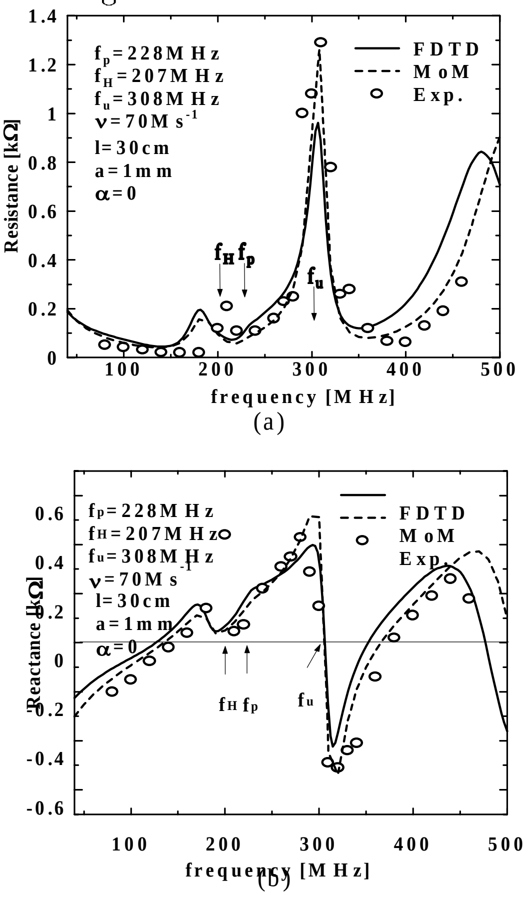

Figure 3: Input impedance of dipole antenna in an anisotropic plasma(Parameter 1).

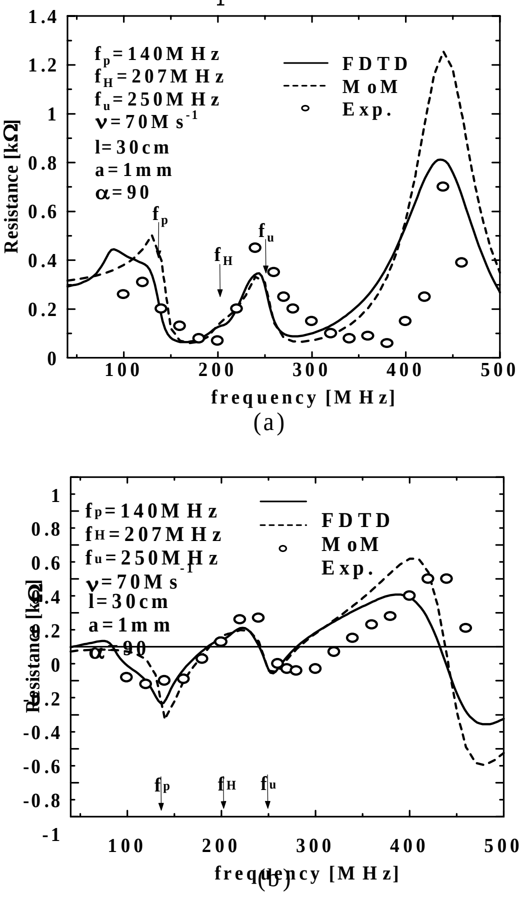

Figure 4: Input impedance of dipole antenna in an anisotropic plasma(Parameter 2).