Study on Frequency Drift Phenomenon of Time Varied Plasma in 1D Metal Resonant Cavity

Bixue Zhou, Xiaoyue Li, Lixia Yang
Department of Communication Engineering
Jiangsu University
Zhenjiang, China
lixiayang@yeah.net

Lijuan Shi
Department of Physics
Jiangsu University
Zhenjiang, China

***Abstract*—In this letter, a frequency drift phenomenon is simulated, when the electromagnetic wave is created in 1D metal cavity, by the modified JEC-FDTD method. By using the method, its resonant frequency of metal cavity is obtained under the conditions of the time varied plasma. The results show that the faster the plasma is generated, the more obviously the frequency drift phenomenon.**

Keywords*—*finite-difference time-domain method; time varied plasma; frequency drift;

Ⅰ. INTRODUCTION

Domestic and foreign research on time-varying plasma has generated great interest recently. In practical applications, the plasma collision frequency changes with time and space.[1] For example, plasma coat of aircraft is often a time-varying, non-uniform, dispersive and non-linear medium, it is an electrically anisotropic medium when an external magnetic field is applied. Plasma is generated when the aircraft reentry the atmosphere with high speed[2][3]. Due to their existence, they strongly interfered or even interrupted the connection between the flying object and the ground monitoring station (radar), and this will threaten the safety of pilots and state property. All show that the study of electromagnetic properties of the time-varying plasma has become one of the most important issues[4].

The Finite-difference time-domain (FDTD) method is a popular and powerful technique for simulate the propagation of EM waves through a variety of media[5]. This paper describes the relationship between plasma generation rate and frequency drift.

Ⅱ. METHOLOGY

A. Governing Equations

In anisotropic dispersion medium collision magnetized plasma, the Maxwell equations and the associated constitutive equations are:

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

$$\nabla \times \mathbf{H} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mathbf{J} \tag{2}$$

In the magnetized plasma, the current density is given by

$$\frac{d\mathbf{J}}{dt} + v\mathbf{J} = \varepsilon_0 w_p^2(r,t)\mathbf{E} + \mathbf{w}_b \times \mathbf{J} \tag{3}$$

where $\omega_p(r,t)$ is time-varying plasma frequency, it is a function of time and space, characterizing the plasma over time and space. v is the collision frequency. ω_p is given by

$$\omega_p = \sqrt{n_e \cdot e^2 / (m_e \varepsilon_0)} \tag{4}$$

where $e = 1.6\times10^{-19}C$,the mass of the electron is $m_e = 9.1\times10^{-31}Kg$.

Plasma distribution using Gaussian distribution, there are two forms, respectively, a single rising edge and a single falling edge. In this paper, we only use the single rising edge, the specific form to meet the following formula.

$$n_e = n_{e0}[1-\exp(-\frac{t}{\tau})]\exp(-\frac{x^2}{4L^2}) \tag{5}$$

where n_{e0} is the maximum free electron density, L is the plasma thickness, τ is plasma relaxation time.

B. Discretization Scheme

Equation (1)-(3) form a closed set of equations that describes the interaction between electromagnetic waves and the plasma. Discrediting (1) and (2) in time-domain, the update equations can be obtained for the magnetic field and electric field, respectively. Here we only give the FDTD update equations for the component E_x and J_x as following:

$$E_x^{n+1}(k) = E_x^n(k) - \frac{\Delta t}{\varepsilon_0 \Delta z}(H_y^{n+\frac{1}{2}}(k+\frac{1}{2}) - H_y^{n+\frac{1}{2}}(k-\frac{1}{2})) - \frac{\Delta t}{\varepsilon_0}J_x^n(k) \tag{6}$$

$$J_x^{n+\frac{1}{2}}(k) = (1-\frac{v}{2}\Delta t)/\left(1+\frac{v}{2}\Delta t\right)J_x^{n-\frac{1}{2}}(k) + \varepsilon_0\omega_P^2\Delta t E_x^{\ n}(k)/(1+\frac{v}{2}\Delta t) \tag{7}$$

C. Numercial Model

In Fig.1, it is a 1D rectangle metal resonant cavity, its size is 60cm. The metal resonant cavity is full of time-varied plasma after the time T_0 point. The change of plasma electron density meets the formula (5), which is depicted in Fig.2.

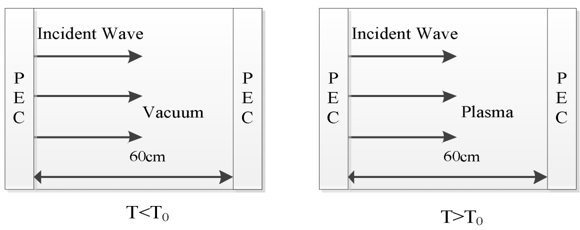

Fig.1.Simulation Model

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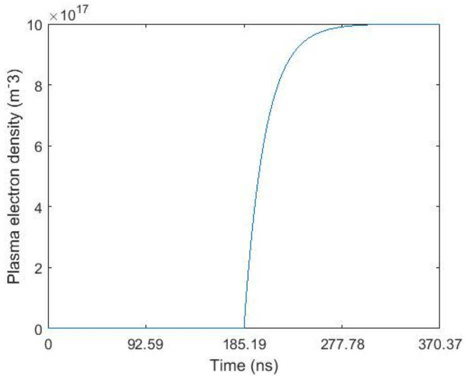

Fig.2. The change of plasma electron density

III. Numerical Results

In the above example, the EM wave has a frequency of $f_0 = 3.2GHz$ in the form of Sinusoidal signal. The plasma electron density is created at 0.1 ns, 10 ns and 100 ns to reach its maximum, where $n_{e0}=10^{18}\ \mathrm{m}^{-3}$, $\delta=1\times10^{-3}$ m , $\Delta t = \delta / 2 / c = 1.67\times10^{12} s$, $v = 5\mathrm{GHz}$.

From Fig.3, we can see that the plasma generation speed is faster, the frequency drift is more obvious. From Fig.4 to Fig.5, as the plasma generation becomes slower, the amount of frequency drift gradually decreases. While in the microsecond order there is a smaller resolution, it is difficult to observe the above results.

From Table.1, it records the frequency drift of four frequencies based on the various plasma generation time. As can be seen from the table data, the frequency drift gradually decreases as the plasma generation time becomes slower. In the μs order of time, it is difficult to observe the results because there is a smaller resolution.

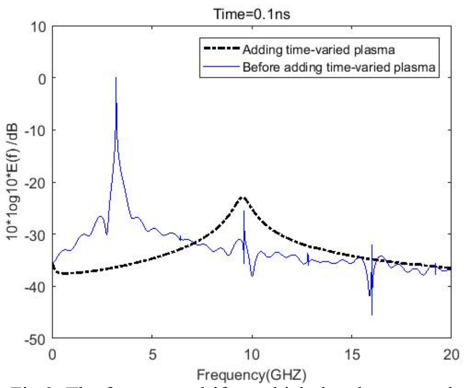

Fig.3. The frequency drift at which the plasma reaches its maximum value in 0.1ns.

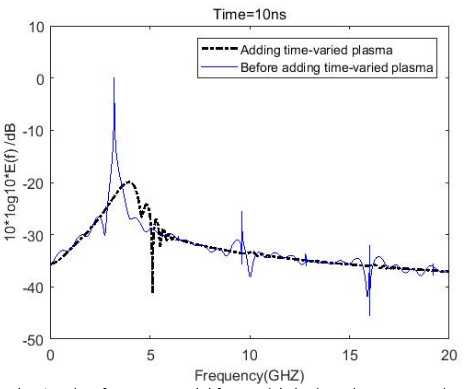

Fig.4. The frequency drift at which the plasma reaches its maximum value in 10ns.

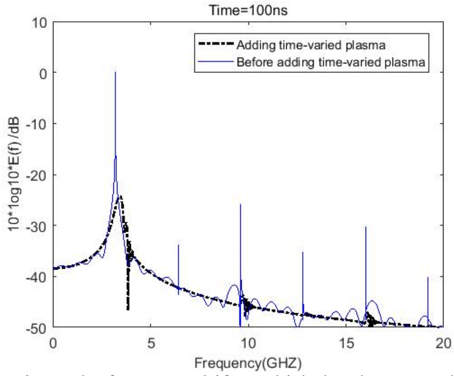

Fig.5. The frequency drift at which the plasma reaches its maximum value in 100ns.

Table.1. Different frequencies of electromagnetic waves in a variety of plasma generated under different frequency drift frequency

Frequency	0.1ns	10ns	100ns	1μs
450MHz	8.97GHz	1.34GHz	508MHz	Frequency shift is difficult to be observed
1.3GHz	9.05GHz	2.25GHz	1.55GHz	
3.2GHz	9.51GHz	3.94GHz	3.43GHz	
5.5GHz	10.54GHz	6.16GHz	5.75GHz	
10GHz	13.42GHz	10.47GHz	10.15GHz	

IV. Conslusion

To summarize, We semi-quantitatively analyze the time-varying plasma frequency shift phenomena of electromagnetic waves in a short simulation time. It is helpful to take advantage of this nature of the project to obtain the electromagnetic wave frequency band that the conventional method is hard to obtain.

References

[1] Ma H, Yang L X, Shi L, et al. A modified FDTD method of EM scattering of dispersive plasma thin layer. International Conference on Microwave and Millimeter Wave Technology. IEEE, 2012:1-4.

[2] Yablonovitch E. Inhibited spontaneous emission in solid-state physics and electronics[J].Phys. Rev. Lett., 1987, 58 (20): 2059-2060.

[3] John S. Localization of photons in certain disordered dielectric super lattices[J]. Phys.Rev.lett.,1987, 58 (23): 2486-22489.

[4] Hojo H, Mase A. Dispersion relation of electromagnetic wave in one-dimensional plasma photonic crystals[J].J.Plasma Fusion Res.,2004,80: 89-90.

[5] Shi L J, Yang L X, Cai Z C, et al. An FDTD absorbing boundary condition for anisotropic media based on NPML[J]. Waves in Random & Complex Media, 2015, 25(2):293-305.