Investigation of the Electromagnetic Wave Propagation in Three Dimensional Plasma

Meng Zhang and Long Li*, *Senior Member, IEEE*
Key Lab. Of Antenna and Microwave Technology
Xidian University
Xi'an China
*lilong@mail.xidian.edu.cn

Abstract **—The characteristics of electromagnetic wave propagation through a plasma array are investigated in this paper. Electromagnetic wave is incident normally in the plasma array at the frequency range from 1 to 10 GHz. Electromagnetic wave will be reflected by the plasma array regardless of the polarization when the wave frequency is sufficiently lower than the plasma frequency. With increasing the operational frequency, the reflection of the electromagnetic wave is getting smaller. Increasing the diameter of the tube ,the reflection of the electromagnetic wave is getting larger. These results are caused by different schemes of interaction with electric field and electrons in plasma. The diameter of the tube is 25 mm and the dimension of commercial fluorescent for simulation. The model is investigated through simulation by using the CST microwave studio software.**

***Index Terms*—plasma, plasma frequency ,CST , reflection.**

I. INTRODUCTION

With the rapid development of space science and technology in recently years, people has extended their exploration area to the interstellar space. While the space plasma environment is the basic condition for people's space exploration activity. The environment of space plasma includes ionospheric plasma environment, the star and the outer space plasma environment, etc.

As is well known, plasma reflects, attenuates, and refracts electromagnetic wave due to the presence of charged particles. Plasma acts as metal when the wave frequency is lower than the plasma frequency which is a function of electron density, and plasma acts as dielectric when the wave frequency is higher than the plasma frequency. The first suggestion of using ionized gas for transmit and receive was by J.Hettinger in 1919 and the first experimental results were done by Askaryan and Raveskii in 1960s [1-3].

In most of those researches, plasma was generated in vacuum chambers or in open air to maintain sufficient plasma volume. Electromagnetic wave was reflected or absorbed successfully, but they needed some special resources such as magnetic confinement or addition of particular organic gases because it was difficult to obtain enough electron density in such system due to the diffusion loss of energized particles [4]. They also needed a lot of energy to maintain plasma. Rencently, a plasma array structure has also been proposed as a reflector or an absorber by some groups [5]-[6]. In those researches, plasma was generated in small gas vessels like fluorescent lamps.

One of the main different points of a plasma array from bulk plasma is that plasma spatial distribution was not uniform since plasma is enclosed in vessels. Due to the difference, the electromagnetic property has large dependence on the frequency of electromagnetic wave. Therefore, it is important to understand the propagation property of electromagnetic wave through a plasma array in different parameters.

In this paper, the electromagnetic property of three dimensional plasma array is investigated in the microwave frequency. Based on the basic knowledge of plasma environment in ionosphere, analyzing the main factors of the space plasma which have influence on the electromagnetic wave transmission and scattering. The plasma parameters create an environment with high controlling capabilities. The model is simulated by practical software CST microwave studio 2016.

II. MODEL AND PLASMA

A. Theory of plasma

Collection of ionized positive ions and free electrons is plasma or fourth state of the matter. For the nonmagnetic isotropic plasma has complex permittivity that is defined by Equation (1) [7]:

$$\varepsilon_r = \varepsilon_0 \left(1 - \frac{\omega_p^2}{\omega(\omega - i\nu_c)} \right) \tag{1}$$

Where ε_0 is the free-space permittivity, ω_p is the plasma inherent frequency [rad/s], ω is the operating angular frequency, ν_c is the electron neutral collision frequency and is the plasma angular frequency [rad/s] that define with Equation (2) [7]-[8]:

$$\omega_p = \sqrt{\frac{n_e e^2}{m_e \varepsilon_0}} \tag{2}$$

Where n_e is the electron density [m-3], e is the charge of ele ctron, m_e is the electron mass,and ε_0 is the free-space permittivity.

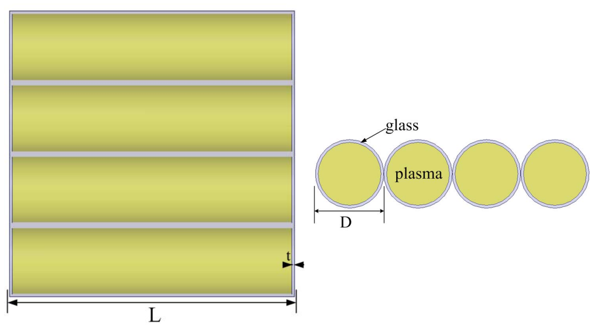
Substituting constant values leads to the approximate useful formula:

$$f_p = \frac{\omega_p}{2} \approx 9\sqrt{n_e}[\text{Hz}] \tag{3}$$

When the operating angular frequency is greater than the plasma frequency ($\omega > \omega_p$), the plasma acts like a classical dielectric medium and in opposite case ($\omega < \omega_p$), plasma acts as a metal. Consequently, depending on the angular frequency, the plasma can transmit or reflect the microwave radiation [9].

III. SIMULATION AND RESULT

Firstly ,the simulation is design of enclosure. In this paper we present a tube with dimension of commercial fluorescent lamp as an enclosure of plasma, Fig. 1. The commercial fluorescent tube that we used is four T8 lamps that have 25 mm diameter.



(a) (b)

Fig.1 the model of the fluorescent lamp. (a)Bottom view. (b)Side view.

The next is simulating the Plasma and set the parameters of the model. To simulate the characteristic of the plasma, we can use the CST Microwave Studio software based on finite integral technique. The behavior of the plasma is given by Drude dispersion model. This model is simplified model which describes simple characteristic of an electrically conducting collective of free positive and negative charge carriers where the thermic movement of electrons is neglected [10].

TABLE I
THE PARAMETERS OF THE MODEL

***L*(mm)**	***D*(mm)**	***t*(mm)**
100	25	1

The dielectric constant of the Drude dispersion model is define by:

$$\varepsilon=\varepsilon_0\left[\varepsilon_\infty-\frac{\omega_p^2}{\omega\left(\omega-i\nu_c\right)}\right] \tag{4}$$

Where ε_∞ is the relative dielectric constant at infinite frequency, generally $\varepsilon_\infty=1$ .When we set $\omega_p=44e9Hz$ and $\nu_c=2.5e9Hz$, we can give the complex permittivity of the plasma by the equation(3), Fig. 2.

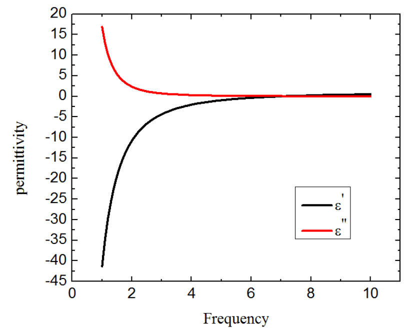


Fig.2. the relationship of the complex permittivity of the plasma with frequency

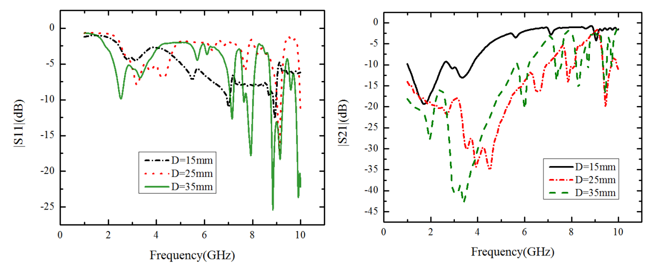


Fig.3 Sparameter simulation at different diameters of the model

Obviously, Increasing the thickness of the plasma increases the reflection and reduction of transmission.

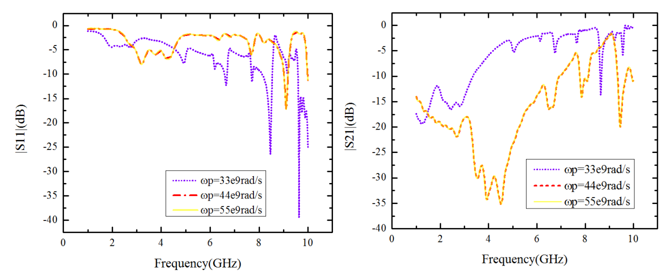


Fig.4 Sparameter simulation at different plasma frequency of the model

The plasma frequency depends on the electron density. The higher the electron density, the higher the plasma frequency.The frequency of the plasma is the cut-off frequency of the electromagnetic wave ,the high electron density can weaken this property, making the cut-off frequency lower.

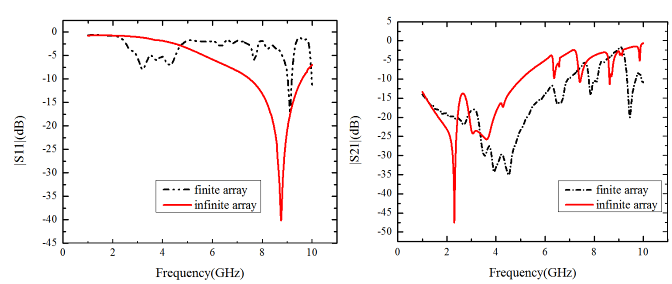


Fig.5 Sparameter simulation about infinite array and finite array

When we extend the finite array into a infinite array, we can observe that the curve is more stable and smooth. At the plasma inherent frequency, there is an obvious resonance point.

■ IV. CONCLUSION

In this paper,we study the case that electromagnetic wave normal incidence into plasma array and analyze the main factors of the space plasma which have influence on the electromagnetic wave transmission and scattering. Furthermore, we simulate the plasma by Drude dispersion model and extend the plasma array into a infinite array. We can know that increasing the wave frequency and the thickness of the plasma, the reflection of the electromagnetic wave was getting smaller.

■ REFERENCES

[1] W. Shen, J.E. Scharer, N. T. Lam, B. G. Porter and K.L.Kelly, “Properties of a Vacuum Ultraviolet Laser Created Plasma Sheet for a Microwave Reflector”, Journal of Applied Physics, 1995, Vol. 78, No. 12, pp. 6974-6979.

[2] G. Borg, J.H. Harris, N. M. Martin, J. Kircher, “Plasmas as Antennas: Theory, Experiments and Applications”, Physics of Plasmas, July 2000, Vol. 7, pp. 2198-2202.

[3] W. Kang, M. Rader, I. Alexeff, “A Conceptual Study of Stealth Plasma Antenna”, Proceeding of 1996 IEEE International Conference on Plasma Science, 1996 , pp. 261.

[4] T. Naito, K. Yamamoto, S. Yamaura, T. Tanaka, H. Ogino, O. Sakai, “Investigation of electromagnetic wave propagation through one-dimensional plasma array”,2015 9th European Conference on Antennas and Propagation (EuCAP),2015,pp.1-5.

[5] I. Alexeff, T. Anderson, S. Parameswaran, E. P. Pradeep, J. Hulloli, and P. Hulloli, “Experimental and Theoretical Results With Plasma Antennas”, *IEEE Trans. Plasma Sci.*, vol. 34, no. 2, pp. 166-172, Apr.2006.

[6] T. Tanaka, Y. Nishioka, Y. Inasawa, K. Yamamoto, H. Ogino, T. Komi, A. Harasaki, M. Sakurai, and M. Doumen, “A study on RCS Reduction by Using Plasma”, in *Proc.* IEICE Electronics Soc. Conf. 2013,Fukuoka, 2013, p.21.

[7] T. Anderson, “Fundamental plasma antenna theory,” in Plasma Antennas. Norwood, MA, USA: Artech House, 2011, pp. 31–36.

[8] U. S. Inan and M. Golkowski, “Introduction,” in Principles of Plasma Physics for Engineers and Scientists. Cambridge, U.K.: Cambridge Univ. Press, 2011, pp. 1–13.

[9]Oumar Alassane Barro, Mohamed Himdi, and Olivier Lafond, “Reconfigurable Patch Antenna Radiations Using Plasma Faraday Shield Effect” IEEE Antennas and Wireless Propagation Letters 1536-1225 (c) 2015

[10] Li Wei, Qiu Jinghui, Lin Shu, Suo Ying “Analysis and Design of Plasma Monopole Antenna” 2011 6th International ICST Conference on Communications and Networking in China (CHINACOM) ©2011 IEEE.