Simulation Study of Plasma Antenna Reconfiguration

Jian Sun
National Space Science Center
Chinese Academy of Science
Beijing, China
sj323@nssc.ac.cn

Yuemin Xu
National Space Science Center
Chinese Academy of Science
Beijing, China
xuym@nssc.ac.cn

***Abstract*—Plasma antenna is a kind of reconfigurable antenna, its antenna frequency and radiation pattern can both be quickly changed by altering the plasma ionizing power and turning on or off certain antenna array elements. This article introduce our HFSS analysis method in the study of plasma antenna and array. As a basic calculation, we simulate the reconfiguration of a two elements plasma antenna array.**

Keywords—plasma antenna; reconfigurable; modeling; HFSS

I. Introduction

Reconfigurable antenna is a promising direction of antenna technology, many methods to realize antenna reconfiguration have been developed[1-2]. Plasma antenna is a new kind of reconfigurable antenna which has some distinctive properties such as high speed reconfiguration and low RCS.

Plasma antenna is mainly construct with ionized inert gas which is sealed in a medium column cavity, we can change the antenna length by altering the input ionizing power. The radiation pattern of plasma antenna array can also be reconfigurable by turning on or off certain ionized antenna elements. The reconfiguration of plasma antenna can be agilely finished within millisecond[3-4].

The National Space Science Center, Chinese Academy of Science is one of the earliest domestic research institute of plasma antenna, we have made up abundant achievements in plasma antenna research[5-13]. In this study, we use HFSS to simulate our plasma antenna prototype and calculate the frequency and directivity reconfiguration of plasma antenna.

II. Simulation of Plasma Antenna and Antenna Array

A. Approximate Modeling of Plasma Antenna

Fig.1 shows our laboratory prototype of plasma antenna. Inert gas is sealed in a vacuum glass cavity, and the glass column cavity is fixed in a copper coupling cavity. The coupling cavity has two wave ports. Driving power is input from one port to ionize high density plasma column, signal power is connected to another port. Because signal frequency is lower than ionized plasma frequency, it can not penetrate through the plasma column but propagate along the plasma surface and radiate to space, like a common metal antenna. Fig. 2 is the inner structure design of the coupling cavity.

Fig. 1. Ionized plasma antenna prototype.

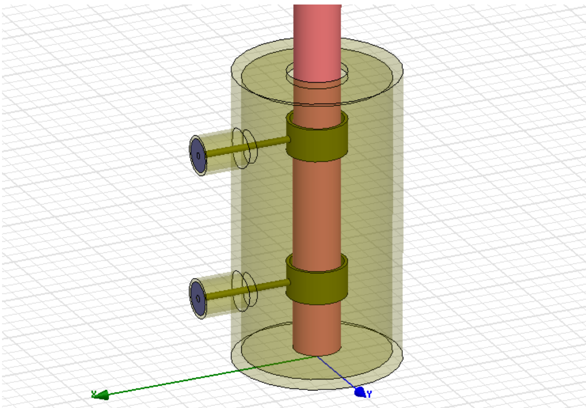

Fig. 2. Inner structure of the exciting cavity.

Fig. 3 is the complete HFSS model of the plasma antenna prototype. To imitate its working state, we draw a finite circular PEC surface as perfect ground. As an approximate modeling, we use a PEC column instead of ionized particles to imitate plasma column. Because we need not use driving power to ionize plasma column, only one port is set as wave port and the other port is set as PEC. Fig. 4 shows the radiation pattern of the 3D model in fig. 3 simulated by HFSS. The calculation result shows its directivity factor is about 1.65 as a common 1/4 lambda monopole metal antenna.

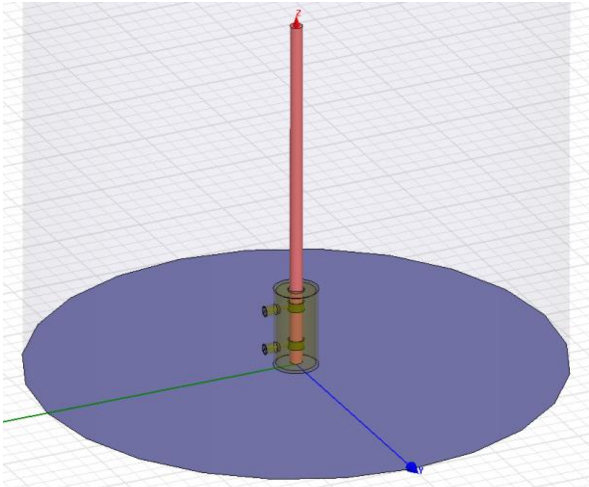

Fig. 3. Approximate HFSS model of plasma antenna.

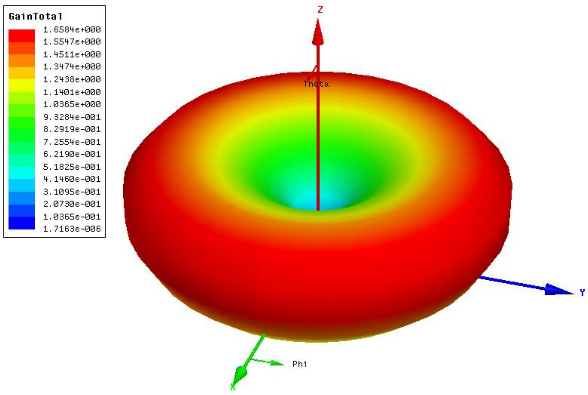

Fig. 4. Radiation pattern of plasma antenna 3D model.

As the RF driving power and radio signal are coupled into the same copper cavity, these different frequency waves may be coupled into each other. The exciting frequency is 150MHz and the signal frequency is 400MHz, so we need to design filters for each port to prevent power intersection. Fig. 5 is the circuit diagram of the filters designed by ANSYS Designer.

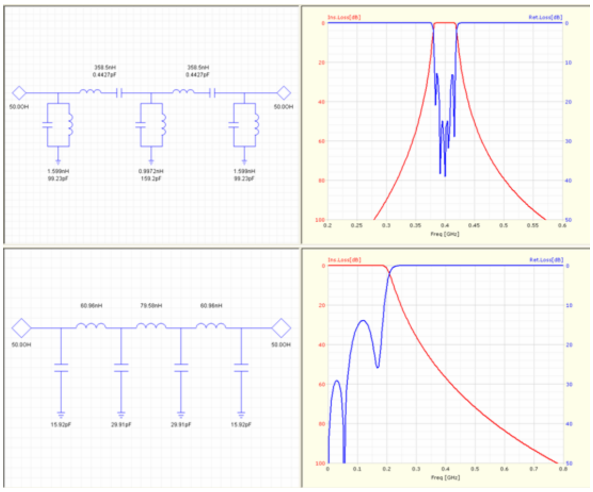

Fig. 5. Filters for the RF ports.

It should be point out that the plasma antenna impedance can not be calculated by common simulation method. Because the plasma antenna is made up of plasma column, the calculating of millions of ionized particles is beyond the calculation capability of any EDA methods. The HFSS model in Fig. 3 use metal column instead of plasma, such approximate simulation can get results as radiation pattern and directivity factor which has been verified by field test. But the impedance situation of plasma particles is far more complex than that of a metal column. So, we have developed special techniques to match impedance of plasma antenna[14-15].

B. Reconfigurable Frequency and Directivity

As the frequency of metal monopole antenna is determined by its length, the oscillate frequency of plasma antenna can be reconfigurable by changing its ionized length. The length of plasma column is determined by input ionizing power when the driving power is coupled from the bottle side of the inert gas cavity. Higher driving power can ionize longer plasma column, therefore the antenna frequency is also decreased, as shown in fig. 7 and Fig. 8.

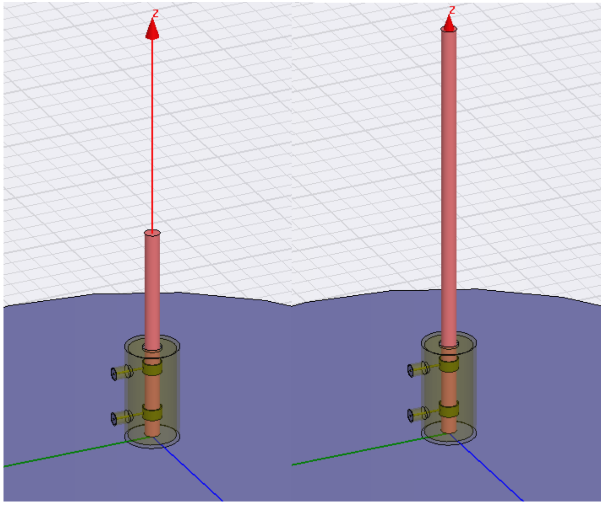

Fig. 6. Reconfigurable length of plasma antenna.

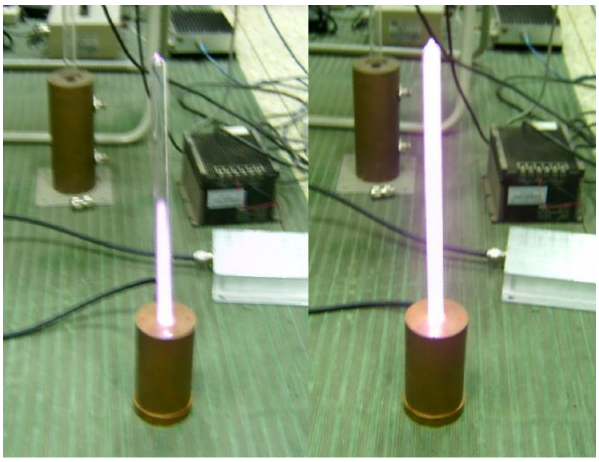

Fig. 7. Reconfiuration test of plasma antenna prototype.

In the left part of Fig. 7, the exciting power is relatively small, and the plasma column is shorter. While adding exciting power, the plasma column length will be fully ionized, as the right part of Fig. 7. So the reconfiguration of plasma antenna frequency can be realized by altering the driving power.

Like a traditional metal antenna, plasma antenna can be make as antenna array. A plasma antenna array can be made up of at least 2 elements, as fig. 8 shows. Being a plasma antenna, any antenna array element can be turn on or off within a millisecond. If an element is turn off by close the ionizing power, it is only a medium tube and do little with microwave. So, we can chose the on or off state of certain array elements to make the radiation pattern reconfigurable.

In the simulation in fig. 3 and fig. 4, we have known that a approximate HFSS model of plasma antenna can be used in radiation pattern simulation. So, we also can use HFSS to calculate the pattern of a simple 2 elements plasma array, and the distance between these elements is 1/4 wavelength. By turning one or two elements and altering the 1/4 lambda phase difference of the elements, we can get at least 4 kinds of radiation pattern, as fig. 9 shows. This two elements array is also reconfigurable in frequency when changing the plasma antenna length. The simulation result is shown in fig. 10.

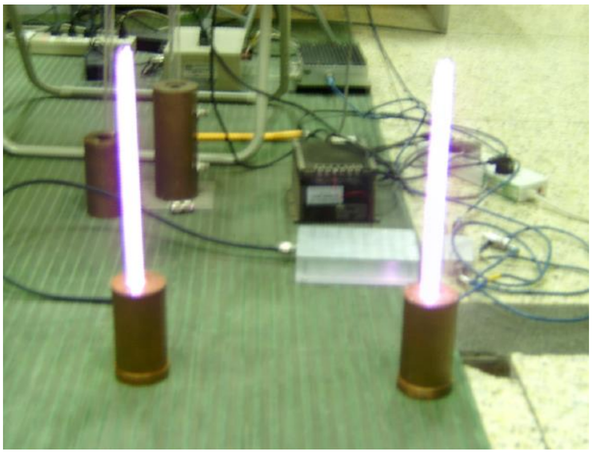

Fig. 8. Two elements plasma antenna array.

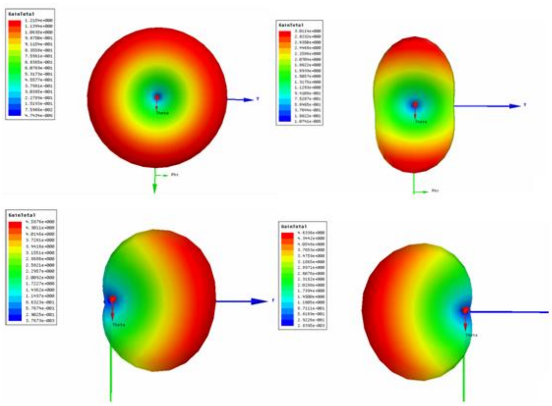

Fig. 9. Two elements plasma antenna array pattern at 300MHz.

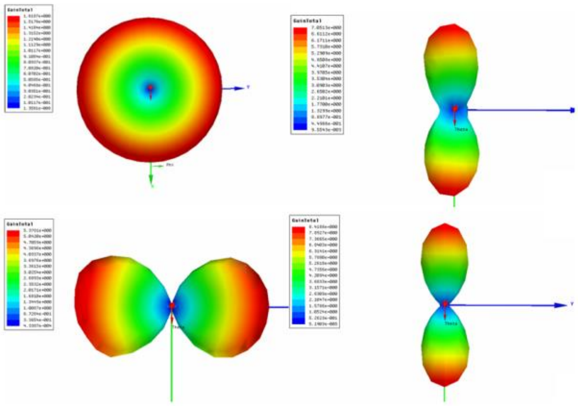

Fig. 10. Two elements plasma antenna array pattern at 600MHz.

The simulation experiment of fig. 10 use the same two elements antenna array of fig. 9, so the distance between the elements is unchanged. Then, we half shorten the length of the two elements as the length reconfiguration of plasma antenna in fig. 7. In the following step, we double the solution frequency, so the elements distance changes from 1/4 lambda to 1/2 lambda. By setting the same or invert phase of input wave and adjusting their relative amplitude, we can also get at least four kinds of radiation pattern, as shown in fig. 10. Therefore, even a basic two elements plasma antenna array can be reconfigurable in both frequency and radiation pattern.

III. DISCUSSION

As a new kind of reconfigurable antenna, plasma antenna can control its length by altering input exciting power. Therefore, the reconfiguration of plasma antenna is very convenient and fast, it do not use MEMS switches or PIN dildos as other reconfigurable antenna. A plasma antenna array can easily realize reconfiguration of both frequency and directivity. Except for reconfiguration, a remarkable character of plasma antenna is low RCS. These characters make a plasma antenna or antenna array very suitable in both active and passive stealth communication.

However, the working frequency of plasma antenna depends on the ionized plasma density, the highest frequency of our present prototype can only reach about 400MHz. In the research of antenna design and manufacture, EDA simulation is a very useful assisting method to save the time and fund of machine work and field test, but plasma antenna is very different with common metal antenna. As we have proved, we can simulate plasma antenna pattern and directivity factor with approximate HFSS model, but we can not calculate plasma antenna impedance and reflection factor.

The plasma antenna array that we discussed here is only a most basic example. According to the simulation of fig.9 and fig. 10, a fixed two element plasma array is reconfigurable by altering its state between two kinds of working frequency and four kind of radiation pattern. If we add the element number of plasma antenna array, more distance and direction combinations can be formed by turning on or off certain plasma antenna elements. Therefore, it can certainly obtain more states of frequency and directivity for reconfiguration.

IV. CONCLUSION

This article reports our reconfiguration research of plasma antenna aided by EDA software, demonstrates the design structure of our plasma antenna prototype and discuss the approximate HFSS modeling in plasma antenna simulation. According to our study, Plasma antenna is very suitable in reconfigurable use, it can agilely reconstitute both frequency and radiation pattern.

ACKNOWLEDGMENT

We thank Hailong Sun, Wenqing Huo and Yaozong Hu for their help in the experiment tests and prototype manufacture. Fengshi Wu and Xiang Zhu also provide very important help and assistance in the earlier research work.

REFERENCES

[1] Xuesong Zhao, Bingzhong Wang, "Research on the reconfigurable antennas," *System Engineering and Electronics,* vol. 25(4), pp. 417-421, 2003.

[2] Yubo Tian, Guannan Tan, "Overview of researches on reconfigurable antennas," *Journal of Jiangsu University of Science and Technology,* vol. 26(3), pp. 271-275, June 2012.

[3] G. Borg, J. Haris, and D.J. Miljak, "Plasma as antennas: theory, experiment and applications," *Physics of plasma,* vol. A247, pp. 2198-2002, July 2000.

[4] G. Borg, J. Haris, and D.J. Miljak, "Application of plasma columns to radio frequency antennas," *Application Physics Letter, 1999,74(5),* pp. 3272-3274.

[5] Zhiwei Liang, Guowei Zhao, Jie Xu, Zhijiang Wang, Yuemin Xu, "Analysis of plasma column antenna using moment method," *Chinese Journal of Radio Science, vol.23,* pp. 749-753, 2008.

[6] Zhijiang Wang, Guowei Zhao, Yuemin Xu, Zhiwei Liang, Jie Xu, "Propagation of surface wave along a thin plasma column and its radiation pattern," *Plasma Science and Technology, vol.9,* pp. 526-529, 2007.

[7] Chao Liang, Yuemin Xu, Zhijiang Wang, "Numerical simulation of plasma antenna with FDTD method," *Chinese Physics letters, vol.25(10),* pp. 3712-3715, 2008.

[8] Guowei Zhao, Zhijiang Wang, Yuemin Xu, Zhiwei Liang, Jie Xu, "Numerical simulation of plasma nonliear phenomena excited by radio frequency wave using FDTD method," *ACTA Physics Sinica, vol.56(9),* pp. 5304-5308, 2007.

[9] Zhiwei Liang, Zhijiang Wang, Guowei Zhao, Jie Xu, Yuemin Xu, "Noise measurement and analysis of plasma antenna," *Chinese Journal of Radio Science, vol.22,* pp. 971-975, 2007.

[10] Guowei Zhao, Yuemin Xu, Cheng Chen, "Calculation of dispersion relation and radiation pattern of plasma antenna," *ACTA Physics Sinica, vol.56(9),* pp. 5298-5303, 2007.

[11] Jian Sun, Yifang Xie, Yuemin Xu, "Progress of UHF/VHF plasma antenna research," *IEEE 10th International Symposium on Antenna Propagation and EM theory, Xi'an,* pp. 23-25, October 2012.

[12] Jian Sun, Yifang Xie, Yuemin Xu, Wenqing Huo, Hailong Sun, "Manufacture and test of practical plasma antenna," *Chinese Journal of Radio Science, vol.28,* pp. 1189-1194, 2013.

[13] Jie Xu, Guowei Zhao, Zhiwei Liang, Zhijiang Wang, Yuemin Xu, "Measurements and anlaysis of plasma comumn discharge impedance," *Chinese Journal of Radio Science, vol.27,* pp. 315-320, 2007.

[14] Zhiwei Liang, Hailong Sun, Zhijiang Wang, Yuemin Xu, "Measurements and anlaysis of plasma input impedance," *ACTA Physics Sinica, vol.57(7),* pp.4292-4297, 2008.

[15] Jian Sun, Yuemin Xu, Hailong Sun, "Research on size reduction of plasma antenna," The 3nd International Conference on Applied Mechanics,Mechatronics and Intelligent System, Nanjing, June 2015, in press.