A Brief Study on Reconfigurable Plasma Antennas

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Abstract : This paper study the reconfigurable characteristics of monopole plasma antennas. Plasma antennas use partially or fully ionized gas instead of metal as the conducting medium to create an antenna. The advantages of plasma antennas are that they are highly reconfigurable and can be turned on and off. The radiated wave profile can be calculated by several numerical methods. The disadvantage is that plasma antennas require energy to be ionized. This paper presents a basic study on plasma monopole antenna using a single fluorescent tube antenna The reconfigurable characteristic of the monopole plasma antenna and its array are analyzed through the simulations. The reconfigurable results of the working frequency and the radiation pattern of the monopole plasma antenna are obtained, the reconfigurable characteristic of the four-element and six-element of the plasma antenna array are analyzed

Key words: *Plasma antenna, Reconfigurable Radiation pattern*

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I. INTRODUCTION

Plasma antennas use plasma elements instead of metal conductors. Plasma is the fourth state of matter after solid, liquid and gases. When a plasma tube is energized with sufficient electrical power, the gas inside the tube will be ionized into plasma state, where it becomes conductive and capable to transmit and receive radio signals. Such antennas are constructed from glass tubes filled with low pressure gases. Plasma elements have a number of potential advantages over conventional metal elements for antenna design as plasma antennas allow electrical, rather than mechanical control of their characteristics. In particular, it is very difficult to detect by hostile radar when the plasma element can be unenergised and if the tube is properly designed. Moreover, antenna arrays can be rapidly reconfigured without suffering perturbation from unused plasma elements. Finally, the effective length of the antenna can be changed by controlling the applied power, allowing its resonance frequency to be varied and therefore the useful bandwidth to be increased.

In this paper, we set up a model of the dipole plasma antenna and study the relationship between the plasma parameters and the radiation characteristic. Then a reconfigurable plasma antenna is designed to analyze with help of four elements and six elements and study the performance reconfigurable plasma antenna. It is observed that array plasma antenna will produce more directive radiation patterns that a single plasma antenna

This report is divided into five sections as follows: Section I and II discusses the introduction and theory of plasma antenna and theory. Part III presents the antenna pattern and the structure of array antenna, Section IV presents the simulation results and Section V provides the conclusion of this paper.

II. PLASMA ANTENNA THEORY

Plasma is a dispersive medium. The reflective index of uniform plasma under low electron-neutral collision rate assumption is as follow:

$$n^2 = \epsilon_r = 1 + \frac{\omega_p^2}{\omega(j\nu - \omega)} = 1 - \frac{\omega_p^2}{\omega^2 + \nu^2} - j\frac{\nu}{\omega}\frac{\omega_p^2}{\omega^2 + \nu^2} \qquad (1)$$

where

ϵ_r is complex relative permittivity of plasma [F/m], ω is the frequency [rad/s], ν is the electron-neutral collision frequency(Hz). ω_p is the plasma frequency given [rad/s] by

$$\omega_p = (n_0\, e^2 / m_e\, e^2)^{1/2} \qquad (2)$$

n_0 is the electron density [m^{-3}], *me* is the electron mass [*kg*] *e* is the charge of the electron [*C*].The collision frequency is given by

$$vp = n_e\, k(T_e) \qquad (3)$$

where *k* is Boltzmann's constant and T_e is the free electrons temperature within the plasma (the measure of kinetic energy of free electrons). When the plasma electron density is large enough, the plasma shows good electrical conductivity,

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which can effectively act as an antenna radiating elements. The conductivity of plasma can be expressed as follows:

$$\sigma = \epsilon_0 \frac{\omega_p^2}{v} \qquad (4)$$

From Eq.(4), we find that the conductivity σ depends on ω_p and ν in the plasma. If ω_p or ν varies, σ will be changed, which results in different characteristic of the electromagnetic wave .Following the analysis of [8], the plasma density is found from a power balance in which the power absorbed per unit length by the plasma from the surface wave the plasma column is balanced by the power per unit length lost to the walls from the plasma by the migration of electron-ion pairs at the Bohm velocity. According to this relationship, the availability of plasma density n_0 and effective length of the antenna h_0 are expressed as follows:

$$n_0 = A(P)\sqrt{P_0} \qquad (5)$$

$$h_0 \approx B(P)\sqrt{P_0} \qquad (6)$$

Where P is filling press, P_O is input power. Equation (5) and Equation (6) show that for a given pressure, plasma density and effective length of the antenna should increase as the square root of the applied power. Hence, given a transmitting frequency, it should be possible to produce the correct plasma density and effective length of the antenna for a dipole antenna by controlling the applied power. However. since the plasma density and conductivity of the antenna varies along its length, the physical length of the plasma column is not necessarily the same as the electrical length of the antenna.

III. EXPERIMENT SETUP

A. Construction of Plasma Antenna:

The plasma antenna is constructed using a commercially available fluorescent tube with dimension of length 25 cm antenna and diameter of 12 mm. The gas inside the fluorescent tube is a mixture of argon and mercury vapor. Fig. 1 shows the schematic diagram of experimental setup for plasma antenna.

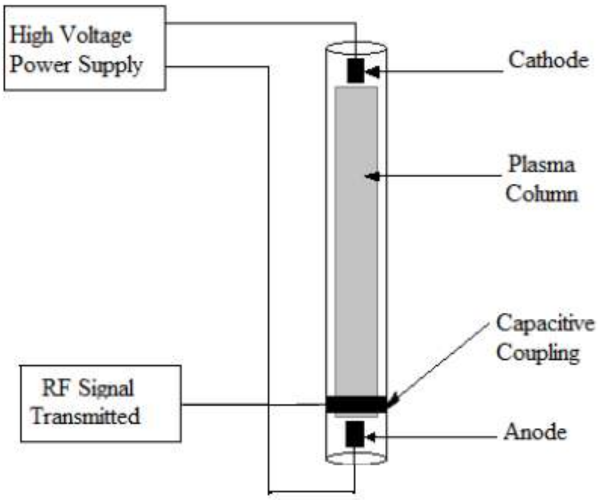

Fig. 1 Setup construction of plasma antenna

The linear plasma antennas excited at both ends by the AC power were employed in the investigation. The gas ionization can be done by applying AC high voltage across the electrodes. The signal of interest is coupled to the antenna by means of capacitive coupling, consisting a copper collar of 30 mm width mounted over the glass tube inside the ground shield made of copper. Ground shielding is a copper cylinder with a height of 40mm and with the diameter of 35mm.The shielding is closed from the top and bottom side by means of two circular copper sheaths having a circular opening at the center to pass the gas tube through it.A coupling sleeve is positioned at the lower end of the tube as an input terminal, which is used to connect the plasma tube with external signals and measuring equipments. The coupling sleeve is connected to circular aluminum with radius 40mm. Fig. 2 picture of constructed monopole plasma antenna.

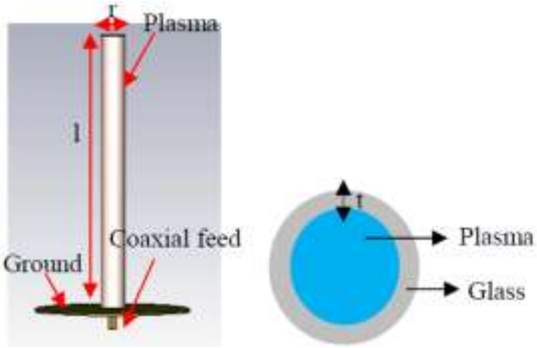

Fig. 2: Simulation diagram of monopole plasma antenna

One must distinguish the difference between the plasma frequency and the operating frequency of the plasma antenna. The plasma frequency is a measure of the amount of ionization in the plasma and the operating frequency of the plasma antenna is the same as the operating frequency of a metal antenna.

B. Reconfiguration of Antenna Length:

Plasma antenna uses vacuum glass column cavity to contain low pressure inert gas such as argon or helium. The input RF power will ionize inert gas into plasma and form plasma column as antenna element. Fig.3 shows the inactive state and active state of a plasma antenna. When the plasma column is ionized to enough plasma density, it can act as a metal column. In field test, our plasma antenna prototypes have reach equal performance as a metal antenna, such as gain, noise and radiation pattern.

As a sort of gas state antenna, the ionized length of plasma column can be determined by input RF power. Therefore, the working frequency and port impedance of a plasma antenna is reconfigurable by altering the input ionizing RF power. But, the accurate control of plasma column length is actually difficult because the ionizing length is not in proportion to input RF power.

Figure 3. Unionized and ionized plasma antenna.

The plasma column is initially ionized from the bottom of gas cavity. As the input ionizing power increase, the plasma column gets longer until the whole cavity is ionized. To a common metal antenna, when we change its working frequency, its impedance is also changed. But a plasma antenna can agilely maintain its impedance by altering its antenna length as Fig.4 has demonstrated. By this means, a single plasma antenna can be used in a very wide bandwidth. Because the reconfigurable antenna length/frequency is controlled by input RF power and no mechanical device is involved, the ionizing length of plasma column antenna can be rapidly reformed within millisecond[6-9]

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Figure 4. Reconfiguration of plasma antenna.

C. Reconfigurable Characteristics Array Antenna

In case of metal antennas, the reconfigurable characteristics are realized through the antenna array, In such case many mental antennas are arranged in particular manner to form the antenna array called the phased array antenna. The reconfigurable ability phase array antenna has strong, but it need to be proper design and controlled precisely. There many forms of antenna array like, the broadside array, the endfire array, the collinear array, the line arrays, plane arrays, and circle arrays. In this paper we study the monopole plasma antenna based on circle arrays. In this, each monopole plasma antenna are placed with equal distance around the circle. The reconfigurable characteristics of the plasma antenna array can be achieved by changing physical states of one or more plasma monopole elements of the antenna array. The commercial software like CST Microwave Studio, HFSS are used to simulate electromagnetic field radiation behavior of the plasma antenna array.

IV SIMULATION RESULTS

A.Plasma Antenna Array with Four-elements:

The plasma antenna has many different characteristics. The radiation pattern of reconfigured is observed at azimuth angle of 360^0 degrees. At this, the plasma antenna can be turned-on very quickly, so the plasma antenna can be reconfigured with very high speed. The arrangement of the four element plasma array shown as Fig.5. The simulations are made under the following assumptions. The frequencies of plasma elements are set at f=1.5*GHz* and the collision frequency(v_P) is 150MHz. The plasma frequency of element at azimuth angle of $\Phi = 0^0$ is 6 *GHz*,and plasma frequencies of other three antenna elements are at constant and the frequency of elements in azimuth angle $\Phi = 0^0$,and $\Phi=180^0$ are 6*GHz*, and plasma frequency of other two plasma elements are at constant. The radiation patterns of the plasma array under these assumptions are shown as Fig.6, it can be observed that the radiation pattern will be strengthened in the certain direction with changing of the plasma frequency in certain angles of direction, hence the plasma array can be reconfigured.

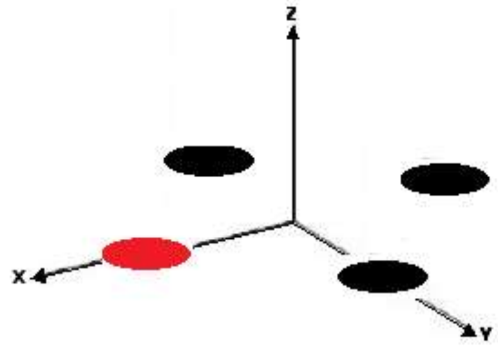


Fig.13. Four-element plasma antenna array

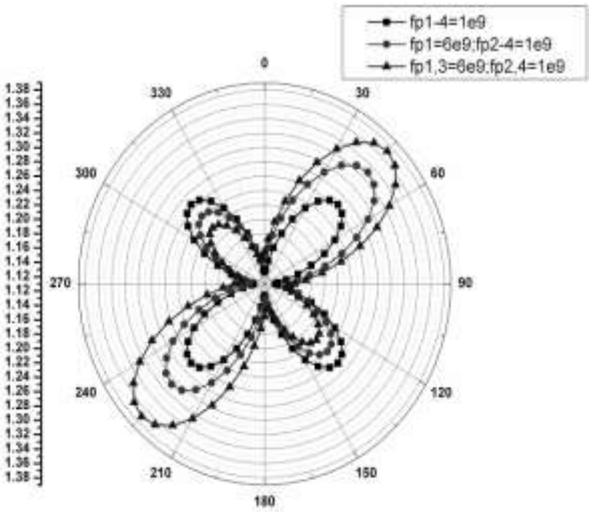


Fig.6. Radiation pattern of four-element plasma antenna array

B. ***Plasma Antenna Array with Six-elements:***

The arrangement of six-element plasma antenna array are shown in Fig.7 With help of this arrangement we study and analyze the reconfigurable characteristics of the six-element plasma array antenna. For six-element plasma antenna array the following assumptions are made,the frequency of the elements of plasma array is 1.5 *GHz* and the frequency of the plasma element azimuth angle $\Phi = 0^0$ is at 3*GHz*, frequency of other five elements in the array is at 1.5 *GHz* .The third assumption is the frequency of the plasma element at azimuth angle $\Phi = 0^0$ is 6*GHz*, and frequency of other five elements are remains at 1.5*GHz* .

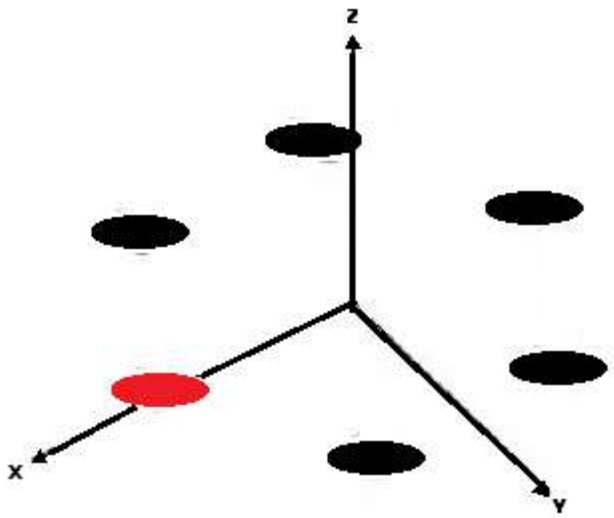
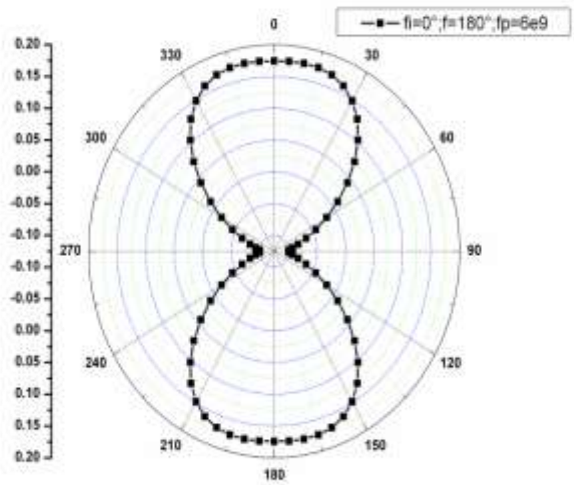
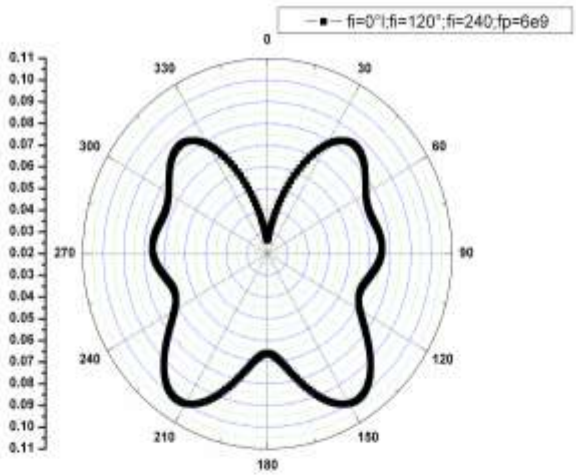


Fig.7. Six-element plasma antenna array

From the simulation results it is observed that the six-element plasma antenna is nearly an Omnidirectional antenna as shown in Fig.8, it can be observed that the radiation pattern will be strengthened in the certain direction with changing of the plasma frequency in certain angles of direction, and the radiation pattern is also changed obviously, so the radiation properties of plasma array is depends on the method of controlling frequency. The radiation patterns of six-element plasma array are shown in the (a),(b) of Fig.8. Here, the multi-wave in radiation pattern also can be achieved through these methods.



(a)



(b)

Fig.8. Multi-beam in radiation pattern of six element plasma antenna array

V.CONCLUSION

This paper reviews recent work and applications of plasma antennas. Plasma antennas use partially or fully ionized gas instead of metal as the conducting medium to create an antenna. The reconfigurable characteristic of the monopole plasma antenna and its four-element, six element array are analyzed through the simulations. The reconfigurable characteristic at different plasma frequencies and the radiation pattern of the monopole plasma antenna are studied. The radiation pattern will be strengthened in the certain direction with changing of the plasma frequency in certain angles of direction in four element plasma antenna array and from the simulation results, the six-element plasma antenna is nearly an Omnidirectional antenna The experiments and research results of this review paper are useful to the further application of plasma antenna and its array.

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