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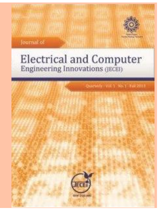

Design and Fabrication of Plasma Array Antenna with Beam Forming

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ABSTRACT

In this paper, the design and implementation of plasma antenna array with beam forming is discussed. The structure consists of a circular array of plasma tube enclosed in a unipolar UHF band monopole antenna. Beam forming is possible by stimulated plasma tubes. The combination of the above antenna with plasma excitation controller makes a beam forming smart antenna. An experimental model in UHF band is fabricated that shows a good agreement between the simulated and measured results.

1. Introduction

Ionized gas was proposed as the fourth state of matter in 1879 by the English physicist, Sir William Crookes. Plasma is a collection of ionized positive ions and free moving electrons. Ionized gases are good conductors for electricity [1]. Plasma can be generated by electron impact ionization, heating the gas, photo-ionization or a DC high voltage.

Plasma antenna is a general term which represents the use of ionized gas as a conducting medium instead of a metal. In this type of antenna, plasma is used to receive or send different signals. The gases used to make this condition, can be argon, neon, mercury, helium or a combination of them. The gas inside a shield which has a specific shape and structure, is held in a specified pressure. By creating an electrical discharge in various forms, the gas is inflamed and considering the necessary conditions, it obtains metallic properties. By satisfying the metallic conditions for plasma antenna, it is ready to send or receive electromagnetic signals.

Plasma antennas are constructed by an insulating tube filled with low pressure gases. The plasma is rapidly created and vanished by applying proper DC voltages. When the antenna is off, the plasma is non-conducting and therefore the tube is transparent. When the plasma is on, it exhibits a high conductivity. The main advantage in using plasma antenna instead of metallic elements is that they allow an electrical rather than mechanical control.

Usually a commercial tube, designed for lighting purposes, has been used to create the plasma column. Plasma environment in terms of electromagnetic properties is an anisotropic, non-linear and dispersive environment that the parameters like σ, μ and ε can be varied due to the frequency and other factors. For different frequencies and densities of ionized gases in plasma, different reactions and properties can be observed. By changing the plasma parameters, such as the electron concentration and collision rate, a significant part of the radiation in the environment can be absorbed, scattered or passed away. Plasma absorption of electromagnetic waves is used for stealth applications [2].

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

$$n^2 = \varepsilon_r = \varepsilon_r' - \varepsilon_r'' = 1 - \frac{\omega_p^2}{\omega(\omega - j\upsilon)} \qquad (1)$$

where

$$\omega_p = \sqrt{\frac{ne^2}{m_e\varepsilon_0}} \ , \ \upsilon = n_e\sqrt{\frac{KT_e}{m_e}} \qquad (2)$$

where ω_p is the plasma frequency, ω is operating frequency and υ is the collision frequency. It should be noted that the plasma frequency is completely different from the operating frequency.

If $\omega > \omega_p$, then the propagation constant due to $\gamma = \alpha + j\beta = jk_0\sqrt{\varepsilon_r\mu_r}$, is purely imaginary. This means that there is no reflection from the plasma environment, so waves can pass through the plasma environment and if $\omega < \omega_p$, the propagation constant is purely real and plasma environment acts like a metal. The difference is that as soon as the power supply is turned off, the plasma quickly becomes a neutral gas. Hence, the plasma can be used as a radiator for radiation. Previous experiments of Borg et al have demonstrated plasma antenna for HF, VHF and UHF band communications with similar efficiency and radiation pattern of a metal whip antenna [3].

In addition, further studies on the first resonant frequency of the plasma monopole antenna show that the resonant frequency of the antenna increases with increasing plasma frequency. Thus, controlling the resonant frequency of the antenna over the plasma frequency is possible too [4].

2. Reconfigurable Antenna

Reconfigurable antennas refer to those that can change or reconfigure their characteristics. Nowadays, various applications of wireless communications at different frequency bands need different radiation patterns. Although regularly by designing different antennas, these requirements can be met. Practically, the physical size of the system and electromagnetic interference caused by the coupling of each antenna affects the implemented system seriously. Hence, designing the antenna that can be changed according to the requirements of its features, can lead to simplification and better performance in smart telecommunication systems. In some areas, where the space is limited, such as airplane, small ship and satellite, reconfigurable antenna is used to reduce the number of antennas, EM interference and the total RCS of the platform [5]. There are several ways to achieve beam shaping, which one of them is to use an array of driven elements. This technique is presented in [6] where four-element dipole array operates at 5.2GHz. Another N-element monopole array has been studied and presented in [7]. But Monopoles were employed due to the reduction of the physical size of the antenna. The 6-element monopole array has been manufactured on a finite ground plane and Fig. 1 shows the geometry of the antenna.

The antenna prototype has been simulated for several configurations with various numbers of elements (4, 6, 8, and 10 elements) and their performances were then compared.

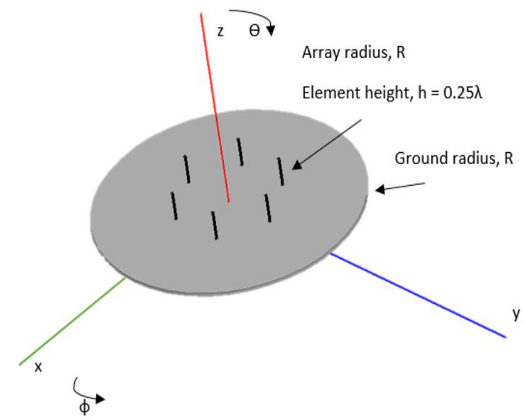


Figure 1: Wire circular monopole array (CMA). Geometry of a 6 - element CMA on a finite ground plane.

For a 6-elements array, the performance of the antenna was better than the other configurations. The excitation model of 2-0-6 (elements 2 and 6 are excited, element 1 is open, and elements 3, 4 and 5 are shorted to the ground plane) is chosen, since it had better directivity in the H-plane. So, this configuration has been optimized by observing the effect of the size of ground plane and the array radius on the antenna radiation pattern. Fig. 2 shows the simulated results for H- and E- planes.

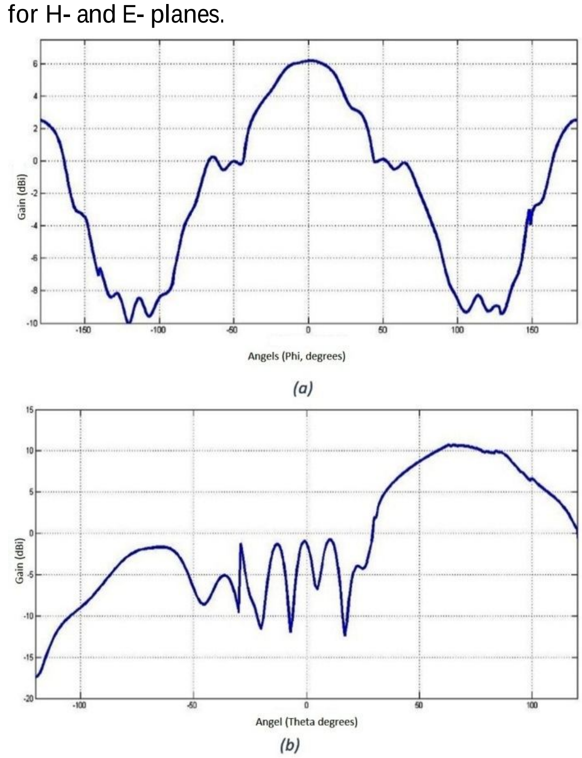


Figure 2: Simulated radiation pattern of circular monopole array antenna: (a) H-plane and (b) E-plane.

3. REFLECTOR

Based on what is said above, one of the advantages of plasma in the fabrication process of antennas is the ability of removing the plasma environment that acts instead of metal, when necessary and that can happen in a fraction of a second too. This fact can be used to hide the antenna in electromagnetic and radar applications. This advantage is worth much more in military applications, especially in large antennas (e.g. reflectors).

Another use of turning on/off plasma is to rotate antenna radiation pattern electronically and thus sweeping the main beam non-mechanically. In this technique, reflector consists of a number of tubes of plasma in circular form. In some applications, all of them are independently capable to switch on or off. Controlling these elements can shape and steer the beam.

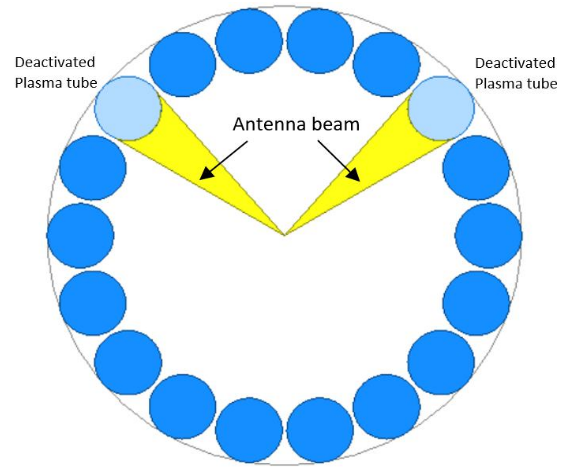
4. WIDE BEAM SCANNING AND BEAM FORMING

Igor Alexeff, Ted Anderson and their group have published several great works in designing plasma using antenna such as smart plasma antenna in [1] and [8]. The plasma elements are in circular coordination to obtain extra possibility of beam steering, shaping and scanning. The large fluorescent lamps are used as the plasma source and thus the resultant antenna is quite bulky. Fig. 3 (a) shows the schematic of the antenna. De-activated elements will create a plasma window and allow directional beam to emerge. The plasma window can be varied accordingly with a number of de-activated elements. The conception of smart antenna was realized at 2.5 GHz and the final antenna was fabricated as shown in Fig. 3 (b).

Generally, a reflector antenna operating at 2.5 GHz does not need tall reflecting elements. Therefore, it is enough to ensure that the reflecting elements are little taller than the resonating element (>λ/4). Thus, due to the size of plasma element used in [1], hence some parts of the fluorescent lamp (FL) need to be covered as shown in Fig. 3 (b).

5. SUGGESTED STRUCTURE

The structure used in this paper is an array of fluorescent tubes as shown in Fig. 4. The circular plasma array antenna is constructed from 12 glass tubes. The tubes are inserted inside a metallic box placed on the ground plane. The array radius is 14cm and the height of the fluorescent lamps is 35cm. A metallic monopole antenna has been placed at the center of the arrays and its length was optimized for 750MHz. The antenna has been fabricated based on the simulation results. The H-plane radiation pattern is shown in Fig. 5(a) at two different states. When all the elements are de-activated or just when 4 of them is off.



(a)

(b)

Figure 3: (a) Schematic of beam forming for a plasma windowing directional antenna. (b) Photograph of initial smart plasma antenna [1].

According to this figure, the directional radiation pattern is increased by 8 dB when the 8 tubes are turned on. By selecting the off pipes, the radiation pattern can be rotated at the azimuth plane. Fig. 5(b) shows the measured and simulated radiation pattern which are in good agreement with each other.

The feature of designed array is that by turning off one or more tubes, the radiation pattern can be rotated to the de-activated tubes in the H-plane. The rotational speed of the electronic circuit of the tube stimulator (that controls the radiation pattern and the variation speed) is much faster than the speed of the mechanical switches. By designing a suitable controller, the rotational speed and direction of the rotation can be adjusted at the desired state.

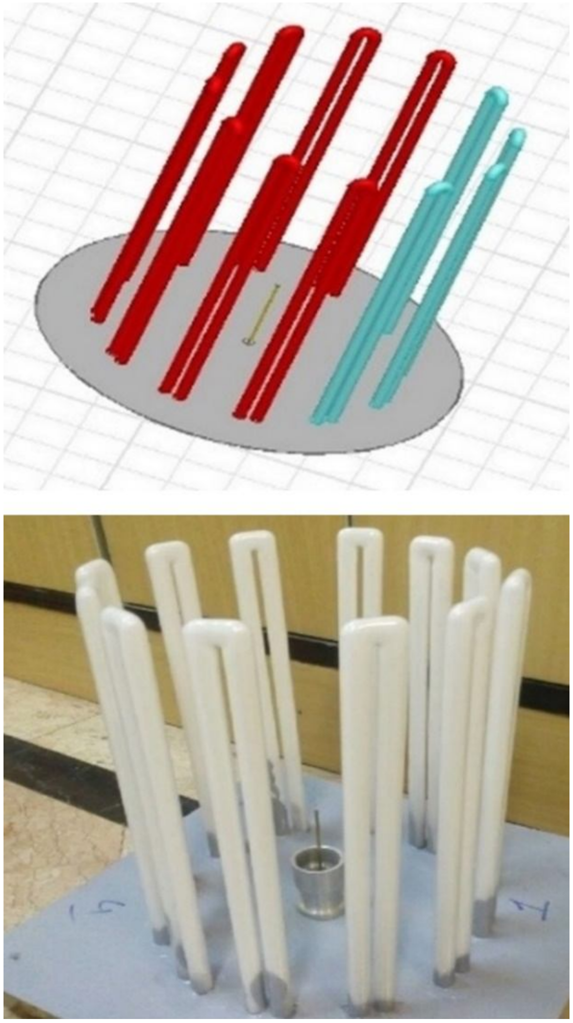
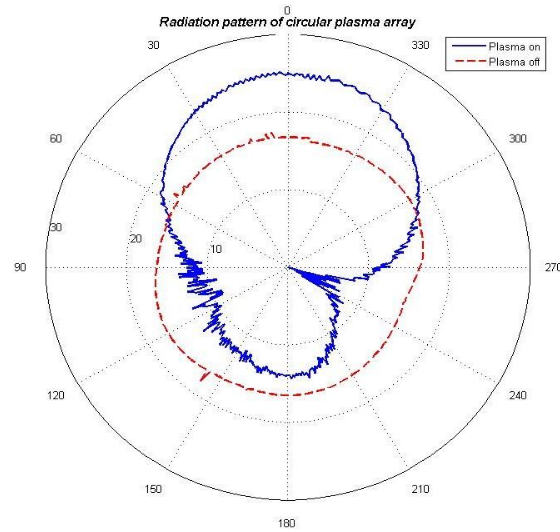
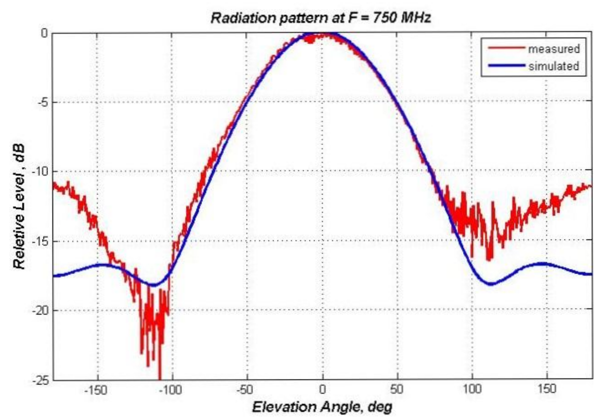


Figure 4: Designed and fabricated model.



(a)



(b)

Figure 5: (a) Measured radiation pattern at two different situations. (b) Comparison between the simulated and measured radiation patterns.

6. Conclusion

A new type of plasma antenna with circular array has been demonstrated. Because the beam steering of this array antenna does not rely on mechanical switches, therefore there is a quick control on the radiation pattern. The feature of the array is that the speed of the rotation of the pattern and its direction are adjustable with a simple electronic circuit. The circular array plasma antenna shows 8dB gain in UHF band. Measurement and simulation results are well-matched which reflect on the accuracy of the design method. The advantage of this design is simple fabrication and the use of commercial and cheap components as the radiation elements. Another feature of this scheme is that when the radiative elements are off, the radar cross section of the antenna array has the minimum possible value than the corresponding metal elements.

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BIOGRAPHIES

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