Performance and Radiation Patterns of A Reconfigurable Plasma Corner-Reflector Antenna

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***Abstract*—A novel reconfigurable plasma corner reflector antenna is proposed to better collimate the energy in forward direction operating at 2.4GHz. Implementation of a low cost plasma element permits beam shape to be changed electrically. The maximum measured gains are 5.7dBi, 10.8dBi and 10.5dBi for the omnidirectional, single and double beam shapes respectively.**

***Index Terms*—Corner reflector antenna, plasma corner reflector antenna, plasma antenna, reconfigurable antenna, reconfigurable plasma antenna.**

I. INTRODUCTION

SINCE many years ago, reflecting surfaces have been used widely in order to steer a beam in the forward direction in antenna systems. Basic reflector antenna that uses reflecting surfaces is known as corner-reflector antenna (CRA). The CRA was first introduced in 1940 by John D. Kraus [1] and known to have about 9-14 dBi gain. Most of CRA use classical antennas such as dipole as a feeder and two flat sheets intersecting at an angle (known as included angle) as the reflector elements. However the simplest design of CRA will suffer from wind effect if it is mounted in the open space. Therefore, one way to eliminate this problem is by replacing the flat surfaces with wire grids. Indeed, its performance is comparable with flat reflecting sheets. Basic guide to design CRA is accessible and well documented in many antenna reference books such as in [2], [3]. Other than forwarding plane wave, circularly polarized CRA was first introduced in [4]. The earliest study on the effect of several lengths and widths of reflecting surfaces on CRA radiation pattern has been carried out in [5]. In addition, many techniques to increase gain of CRA were proposed in [6-8]. A quad CRA in [9] and reactively controlled CRA in [10] were proposed to work at 2.4GHz. A mechanical approach of achieving variable beamwidth by changing the included angle of CRA was proposed in [11]. The design was simulated and measured with the feed-to-vertex spacing is fixed. Generally, beam shaping and beam steering by using plasma reflector are very promising profiles, especially ability of plasma to be reconfigured electrically which is impossible to be done by metal elements.

Unlike, parabolic reflectors, CRAs are uncomplicated in design since they eliminate the crucial part of focal point for a driven dipole and the action of the reflector is not critical as to frequency [1]. In fact, the parabolic reflectors provide slight or no improvement over CRA of comparable size in terms of performance [1]. John D. Kraus claimed that by changing the feed-to-vertex spacing, s with the same included angle, α the beam can be varied from single beam into dual beams. However, with this approach, the s needs to be altered mechanically. For that reason, as proposed in this letter, instead of changing the s, an electrical switchable beam shape is implemented. There is no need to vary the location of the feeder since this method exploiting plasma characteristics [12], [13]. Only by energizing and de-energizing several plasma elements in seconds, omnidirectional pattern can be easily transformed into several forward beams. In other antenna design [14], an idea of using plasma posts for reconfigurable disc antenna was theoretically investigated.

To the best of our knowledge, there is no realization of CRA at any frequency band that has used other than metallic materials as an element except in a simulation proposed in [15]. Hence, this letter is aimed to present simulation and experimental results in order to verify the performance and the radiation patterns of a novel reconfigurable plasma CRA. Three different beam shapes are offered alternately, and the CRA is operating at 2.4GHz. The implementation of compact fluorescent lamps (CFL) has reduced the risk of complexity of impedance tuning which is vital when dealing with parasitic elements in designing antenna arrays. Other than antenna reconfigurability profile, reduced radar cross section (RCS) [16], [17], better gain, good cross-polarization, and high front to back ratio, the overall system is unique because it implements commercially available CFL [18] in order to stay considerably small, compact in size and low cost, if one compares to the elements used in [12] and assumed in [19].

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Comparisons between simulated and measured results in the same configuration are discussed thoroughly in this letter. The simulations were run using finite-element-method-software, CST Suite [20].

II. Plasma Formulation

The isotropic plasma is a dispersive material that has complex permittivity. The permittivity under low electron-neutral collision is given by (1) [12];

$$\varepsilon_r = 1 - \frac{\omega_p^2}{\omega(\omega - iv)} \quad (1)$$

where ε_r is the complex plasma permittivity, ω is the operating angular frequency [rad/s] and v is the electron-neutral collision frequency [Hz]. The ω_p is the plasma angular frequency [rad/s], and its value can be calculated as in (2) [12], [21];

$$\omega_p = \left(\frac{ne^2}{m\varepsilon_0} \right)^{1/2} \quad (2)$$

where n is the electron density [m^{-3}], e is the charge of electron [C], m is the electron mass [kg] and ε_0 is the free space permittivity [F/m]. From (1), the ε_r of the plasma will vary if the ω_p varies and the ω_p can be altered by changing the n as expressed in (2). In order to have the same behavior as a metal, the ω_p of plasma must be higher enough than ω ($\varepsilon_r \langle 0$).

$$\sigma = \varepsilon_0 \frac{\omega_p^2}{v} \quad (3)$$

When the ω_p is large enough compared to the v, the plasma exhibits good electrical conductivity, σ as given in (3) [12]. By varying ω_p or v will give different values of σ and hence the characteristics of electromagnetic wave will be changed.

III. Simulation And Modeling

The CRA elements are made of series of CFLs which are coordinated in V arrangement (Fig. 1). Since the included angle is equals to 90° this CRA is also known as square-CRA [1-3]. The number of CFL elements used in simulation is depending on the length of the reflecting grids of the reflector, L (denoted by L_1 and L_2 in Fig. 1). This is about twice of the distance between monopole antenna and the vertex, s (denoted by s_1 and s_2 in Fig. 1). Since the design has implemented two reflectors on a single ground plane, there are two values of s. The half lambda distance (s=0.5λ) required 8 elements while the lambda distance (s=1.0λ) required 16 elements for both reflector sides. Number of elements used in the simulation has fulfilled minimum requirement of the L [2]. Figure 1 shows the side view of the ground plane with two reflective elements and a feeder monopole antenna. Sets of holes for CFL insertion are also shown in the figure (top view).

The geometric scales of the elements are based on the actual size of CFL. The height of each element measured from the ground plane surface is 54mm, and its diameter is 13mm leaving 0.5mm space gap between the CFL surface and the ground plane (to ease the lamp installation). The ground plane size is 500mm x 500mm and was set unchanged in all simulations. In this design, due to lower part of the CFL, minimum space gap between adjacent elements is 5mm. This space gap has been verified by physical measurement of the actual CFLs which was taking into account the size of the lower part of the CFL (2G7 base size and shape).

In the simulations, a total of 24 elements are arranged to form dual reflectors. However not all elements are set as plasma in every simulation. As the idea is to have three switchable beam shapes, only several of the total elements are in ON state (energized) in order to work as reflector at one time. The dielectric tubes used in the simulation are made from lossy glass pyrex with permittivity of 4.82 and a thickness of 0.5mm. The cold plasma is defined using Drude model (CST software) with 900MHz electron-neutral collision frequency and 6.13x10^{17}m^{-3} electron density. The plasma is

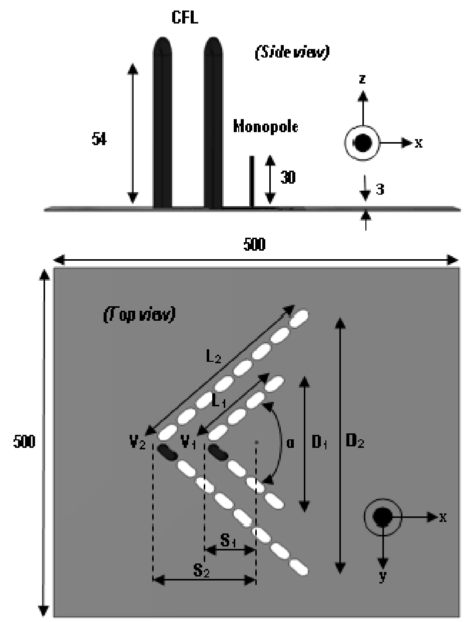

Fig. 1. Geometry of two reflective elements (blue color) and a finite ground plane (units in mm).

assumed to be isotropic and by using (3), the plasma behaves as a poor conductor with σ equals to 19.03S/m. The metal is set as an ordinary annealed copper with σ equals to 5.8x10^{7}S/m. Energy source is supplied by a classical quarter wave antenna and the argon gas was set as air in the simulations.

IV. The Model Realization

The realized model was fabricated on a 3mm thick ground plane as shown in Figure 2. The power to energize the 9Watts CFLs is supplied by a set of electronic ballasts with specification of 220-240V, 50-60Hz. Each of the electronic ballast is controlled by a small single-pole switch and requires 4 wires to be connected to each of the CFLs. Thus, to realize the prototype, 24 electronic ballasts and 24 switches are compulsory. Simplicity, low noise and compact in size are the reasons why electronic ballasts are chosen instead of magnetic ballasts. However, a trade off in terms of increment numbers of connecting wires exists. To simplify, the requirement of 2G7 socket was removed since the CFLs were inserted from the bottom of the ground plane. The CFLs must be vertically aligned with respect to the ground plane surface. Each of the wires is connected to CFL pins by using ordinary wire connectors. A monopole antenna with diameter of 2mm is connected to the feeding line via a 50Ω SMA female connector.

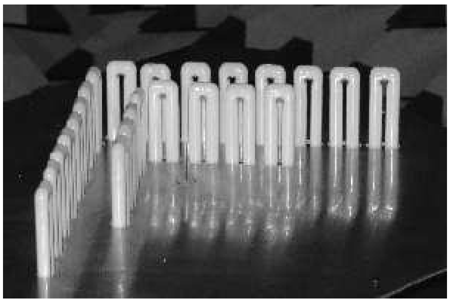

Fig. 2. Realized model with 24 elements.

V. Results And Discussion

Series of measurements were carried out to validate the simulation results. The measurements were performed in a SATIMO 32 anechoic chamber with the peak gain accuracy is equals to ±0.8dBi. Implementation of two reflectors on a single ground plane enables single beam and dual beam shapes to be realized just at your fingertips. The single shape can be changed into dual beam shape within split seconds or even micro seconds with fast switching scheme. In fact, the fastest time taken to change the beam shape from one to another only depends on the time taken by the plasma to decay [13], [17]. Evolution of the beam shapes is shown in Figure 3 and Figure 4, for the H-plane and the E-plane respectively. The radiation pattern for the plasma in OFF state (de-energized plasma) is also shown in the figures to ease comparison.

Unlike the omnidirectional beam shape, the single beam shape could be formed by switching ON all plasma elements with the *s* is equal to 0.5λ, while elements with the *s* is equal to λ are switched OFF. If doing otherwise, a double beam shapes will show up. If all elements are switched ON, the single beam remains without allowing the double beams to emerge. This is an alternative to form single beam shape.

The similarity between simulation and measurements results can be seen from these figures showing that the beam shape of the CRA can be changed from single beam to dual beam shapes and back to classical omnidirectional beam shape alternately. The beam is focused at broadside direction with 3dB beamdwidth equals to ±20°, and the beam is transformed into double beams at phi equals to ±30°. The 3dB beamdwidth for each of the double beams is ±10°. The null is observed at phi equals to 0° in the H-plane which is below -15dB and better result can be seen in the measurement polar plot.

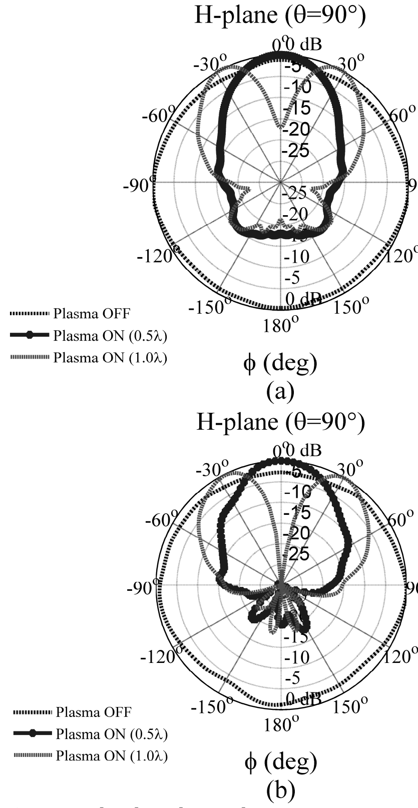

Fig. 3. Normalized H-plane radiation patterns, E_θ component at 2.4GHz. (a) Simulation. (b) Measurement.

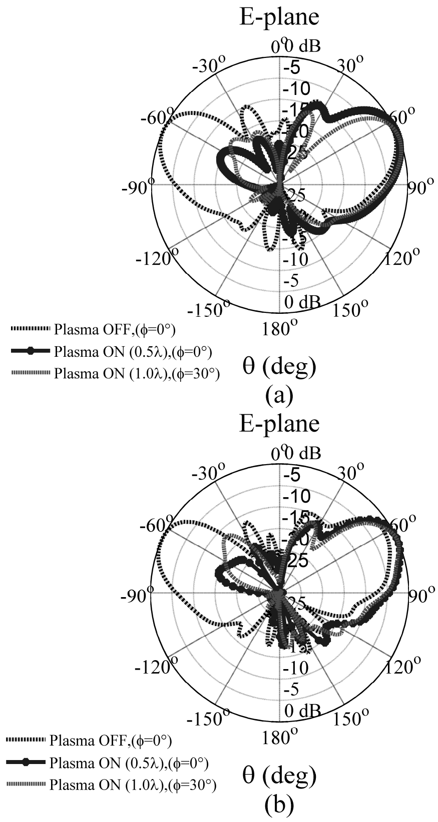

Fig. 4. Normalized E-plane radiation patterns, E_θ component at 2.4GHz. (a) Simulation. (b) Measurement.

The simulated and measured S_{11} are shown in Figure 5. In all configurations, the antenna is matched at 2.4GHz. Wider bandwidths are seen in the measurement results for all cases with respect to the simulation ones are due to mutual coupling effect between the elements. It is worth to mention that, bandwidth more than 1GHz (42%) is achieved when the *s* is equal to half lambda. There are insignificant differences between simulated and measured gains which are less than 1dBi at 2.4GHz for all cases. The simulated and measured

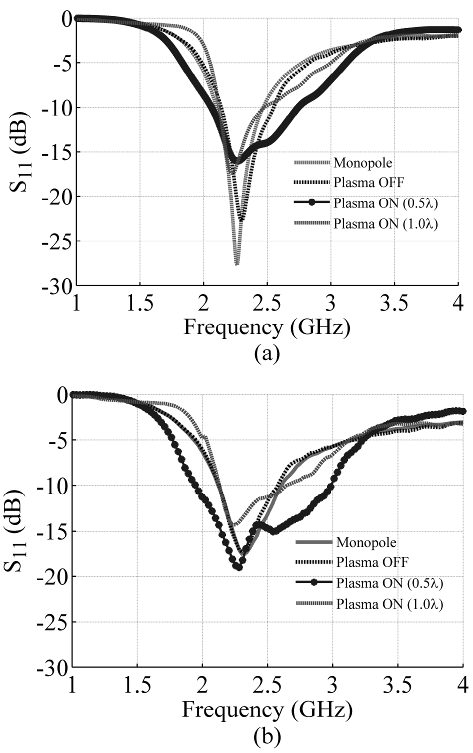

Fig. 5. S11 magnitude parameter comparison. (a) Simulation. (b) Measurement.

gain patterns are shown in Figure 6. The measured gains are 5.7dBi, 10.8dBi and 10.5dBi for the cases of plasma OFF state, *s* equals to 0.5λ and *s* equals to λ, respectively.

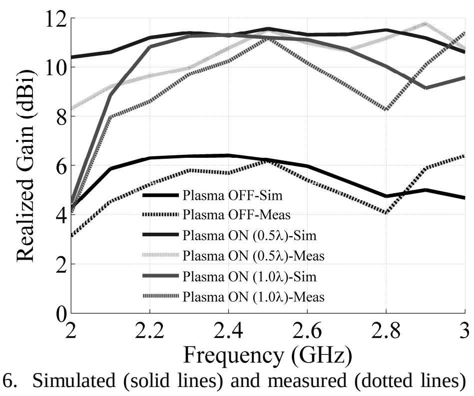

Fig. 6. Simulated (solid lines) and measured (dotted lines) gains for the three states; 1) OFF state, 2) ON state for *s*= 0.5λ and 3) ON state for *s*=λ).

VI. Conclusion

In this letter, a novel reconfigurable plasma CRA is proposed. The novel reconfigurable plasma CRA offers three beam shapes which are electrically switchable from one to another. Up to our knowledge, this is the first work that has validated such design which offers changeable beam shape.

VII. Acknowledgment

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