

Reconfigurable Plasma Antenna Array by Using Fluorescent Tube for Wi-Fi Application

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Abstract. This paper presents a new design of reconfigurable plasma antenna array using commercial fluorescent tube. A round shape reconfigurable plasma antenna array is proposed to collimate beam radiated by an omnidirectional antenna (monopole antenna) operating at 2.4 GHz in particular direction. The antenna design consists of a monopole antenna located at the center of a circular aluminum ground. The monopole antenna is surrounded by a cylindrical shell of conducting plasma. The plasma shield consists of 12 commercial fluorescent tubes aligned in series containing a mixture of argon gas and mercury vapor which upon electrification forms plasma columns. The plasma behaves as a conductor and acts as a reflector in radiation, in the condition where plasma frequency, ω_p , is higher than the operating frequency. From this concepts, when all plasma elements are activated or switched to ON, the radiation signal from the monopole antenna will be trapped inside the plasma blanket and meanwhile when one or more plasma elements is deactivated (switched OFF), the radiation from the monopole antenna will escape. This antenna has the capability to change its patterns with beam direction at 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330° at frequency 2.4 GHz. The proposed antenna has been successfully fabricated and measured with conclusive results.

Keywords

Plasma elements, reconfigurable radiation pattern, monopole antenna

1. Introduction

The term plasma is often referred to as the fourth state of matter. As the temperature increases, molecules become more energetic and transform in the sequence solid to liquid to gas and plasma. Plasma is a collection of ionized positive ions and free moving electrons; usually the ionization degree is very low, less than 1% [1]. Plasma can be

generated by UV laser irradiation, or by laser initiated pre-ionization followed by high voltage break down to form the main conducting channel or by simply using commercial fluorescence tube to serve as reflector, or by much more expensive electron beam [2]. There were also exotic methods like explosion generating plasma antenna for fusion research. The plasma will be present when electron and nucleus that form the atom is no longer able to stay together due to high kinetic energy. It happens due to the electrons are stripped out from the atoms. Plasmas are conductive, and respond to electric and magnetic fields, moreover it also can be an efficient source of radiation. If the sustaining energy is insufficient, plasma will turn into gas form.

Plasma Antenna is a general term which represents the use of ionized gas as a conducting medium instead of metal to either transmit or reflect a signal to achieve radar or stealth or other communication purpose. A plasma antenna is a radio frequency (RF) antenna based on plasma elements instead of metal conductors [3–5]. Such antennas are constructed from insulating tubes filled with low pressure gases.

Recently there has been interest in the use of plasmas as the conductor for antennas, as opposed to the use of metals. Plasma can be rapidly created and destroyed by applying electrical pulse to the discharge tube. Hence plasma antenna can be rapidly switched on and off [6]. When it is off it is non-conducting and invisible to electromagnetic radiations. When it is on, plasma is a good conductor. Plasma is highly conducting and acts as a reflector for radiation for frequencies below the plasma frequency. Because of its unique properties plasma antenna can be as a radiation pattern reconfigurable antenna. Reconfigurable antennas possess very attractive features such as the ability to reconfigure themselves autonomously, to adapt to changes or with the system to perform entirely different functions. The reconfigurable antenna is also capable of providing a single antenna for the use with multiple systems. Most of reconfigurable antennas are constructed by using metallic elements along with active devices. These

active devices were employed to provide switching mechanism for the antennas in order to steer beam in particular directions. In the area of communication, the plasma element was considered as an effective radiator to release the electromagnetic energy just as the metal element did.

Hence, in the present paper the main objective is to design and develop reconfigurable plasma antenna array using fluorescent tube for Wi-Fi application at frequency 2.4 GHz. This paper will also discuss and explain the concept of using plasma elements as reconfigurable antennas rather than using metallic antenna. The new concepts of reconfigurable and beam steering were implemented to design this antenna by using plasma element instead of metal element. The special properties of plasma which can be rapidly activated (switch ON) and de-activated (switch OFF) in few second can be advantage to design and develop reconfigurable radiation pattern antenna. Implementation of reconfigurable plasma antenna array on a single ground plane enables the radiation pattern to reconfigure over 12 directions to be realized just at fingertips. The reconfigurable plasma antenna array is a reconfigurable antenna using a combination of monopole antenna and fluorescent tube function as a plasma medium to produce beam steering control. In contrast to conventional antennas producing fixed directional radiation patterns, the reconfigurable plasma antenna array structure is capable of scanning the beam pattern over 360°. Simulated and measured results of tests on the three antennas are presented and compared to demonstrate the performance of the proposed antennas. These results confirmed that the main beam directions can be pointed to the desired direction by controlling the switched ON and switched OFF of the fluorescent tube.

In this work, the simulation is performed by using the simulation software Computer Simulation Technology (CST) Microwave Studio. This paper is structured as follows: Section 2 describes the antenna design and structure, Section 3 is focused on the analysis of reconfigurable plasma antenna array, in Sec. 4 results and discussion are given, and finally Section 5 is conclusion.

2. Antenna Design and Structure

There are several equations and parameters that need to be considered to design this antenna, especially the behavior of the plasma. To simulate the performance of this antenna, CST MWS software based on finite integral technique is used. The behavior of the plasma is given by Drude dispersion model. The Drude dispersion model describes simple characteristics of an electrically conducting collective of free positive and negative charge carriers, where thermic movement of electron is neglected.

There are two parameters that need to be considered to design by using plasma element: the first one is plasma frequency and the second is collision frequency. Plasma frequency is a natural frequency of the plasma and is

a measure of the amount of ionization in plasma. 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 while the operating frequency of the plasma antenna is the same as the operating frequency of a metal antenna. While for collision frequency, in weakly ionized plasmas, the (charged) plasma particles collide mostly with neutral atoms and molecules. The equation for plasma frequency is shows in (1) and collision frequency in (2).

$$\omega_p = \sqrt{\frac{e^2 n_e}{\epsilon_0 m_e}} \quad (1)$$

where n_e is the electron density [m^{-3}], e is the electron charge [C], m_e is the electron mass [kg] and ϵ_0 is the free space permittivity [F/m]. From

$$v_c = n_e \langle av \rangle \quad (2)$$

where v_c [1/s] is collision frequency, a is collision cross section and v is electron speed. The electron densities are obtained from the numerical calculation of Glomac software [7]. From Glomac, the electron density n_e for each fluorescent tube is equal to $1.13 \times 10^{18} \text{ m}^{-3}$.

In order the plasma element to act as a metal, the ω_p must be higher than the operating frequency. When ω_p is larger enough than the operating frequency, the plasma exhibits good electrical conductivity σ as given in (3).

$$\sigma = \frac{n_e q^2}{m v_c} \quad (3)$$

The structure of the proposed antenna is shown in Fig. 1(a), (b) and (c). The reconfigurable plasma antenna array structure consists of 12 tubes of commercial cylindrical shaped fluorescent tubes that contain the mixture of mercury vapor and argon gas. The ground is circular aluminum plate with thickness of 3 mm and radius of 105 mm. The height of each plasma tube from ground plane surface, L_{PA} is 288 mm and its diameter is 16 mm. The energy source is supplied by a monopole antenna resonating at 2.4 GHz and located at the center of the ground plane. The height of monopole antenna is 35 mm with diameter of 3 mm. The antenna is fed by a standard SMA connector that is located at the middle of the ground. The probe feed (coaxial feed) is a technique that is used in this project for feeding microstrip patch antennas and fed by a SMA connector. SMA connector design is according to specification in using Teflon with dielectric constant of 2.08. The impedance of feeding coaxial transmission line is 50 Ω . The tubes used in the simulation are made from lossy glass pyrex with permittivity of 4.82. The tube wall (glass) has a thickness, $t = 0.1$ mm. The distance between the monopole antenna to fluorescent tubes, D_{BB} is equal to 70 mm. The angle between the centers of two adjacent elements is 30°. The optimized parameters of reconfigurable plasma antenna array are presented in Tab. 1.

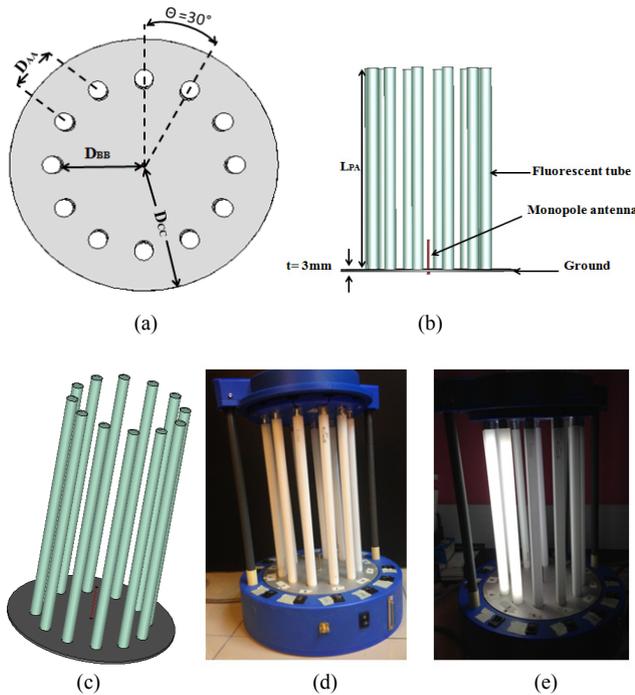


Fig. 1. Geometry of the reconfigurable plasma antenna array: (a) top view, (b) side view, (c) overall structure, (d) photograph of the fabricated antenna prototype, (e) 5/12 plasma switched to ON.

Parameter	Label	Dimension (mm)
Space gap between plasma elements	D_{AA}	36
Distance between plasma element to monopole antenna	D_{BB}	70
Aluminum ground plane radius	D_{CC}	105
Aluminum ground plane thickness	t	3
Length of plasma element	L_{PA}	288
Diameter of plasma element	D_{PA}	16
Length of monopole antenna	L_M	35
Diameter of monopole antenna	D_M	3
Angle between two adjacent plasma elements	θ	30°

Tab. 1. Optimized reconfigurable plasma antenna array specifications.

3. Analysis of Reconfigurable Plasma Antenna Array

In this section, the analysis of parametric study is presented to ensure that the effects were taken place at the desired frequency mode. The target frequency bands is 2.4 GHz. The simulation is performed by using the commercially available simulation software CST Microwave.

Figure 2(a)–(c) shows the simulated parametric studies on the reflection coefficient S_{11} , when some parameters are varied. Figure 2(a) shows the simulated results on the reflection coefficient S_{11} when the distance between the

monopole antenna to the fluorescent tube are varied from 50 mm until 80 mm with increment 10 mm. As depicted in Fig. 2(a), it clearly shows that the distance between the monopole antenna to the fluorescent tube, D_{BB} has a significant effect on return loss and resonant frequency. With $D_{BB} = 50$ mm, the resonant frequency is 1.79 GHz and $S_{11} = -14.04$ dB but when D_{BB} is 60 mm, two resonant frequencies fall, the first one at 1.71 GHz ($S_{11} = -19.99$ dB) and the second one at 2.84 GHz ($S_{11} = -11.79$ dB). When D_{BB} becomes 80 mm the S_{11} is -12.49 dB at frequency 2.18 GHz. So from analysis, the optimum result for the antenna to operate at frequency 2.4 GHz is when $D_{EE} = 70$ mm.

As depicted in Fig. 1(b), the structure of the reconfigurable plasma antenna array contains an aluminum ground.

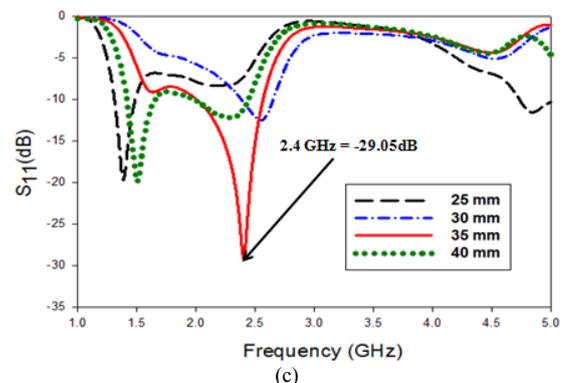
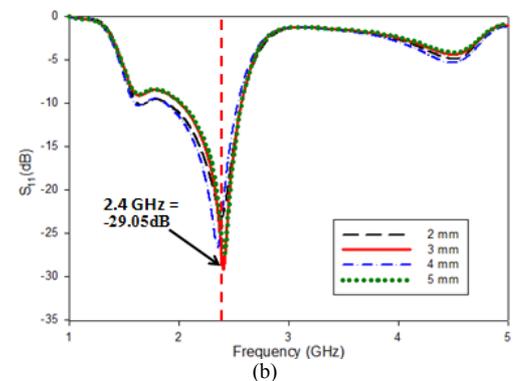
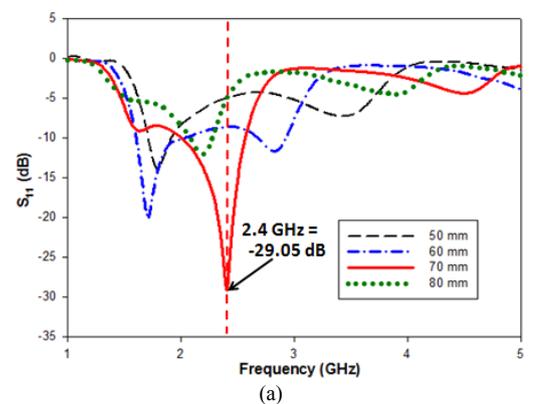


Fig. 2. Effect of (a) the distance between the monopole antenna to the fluorescent tube D_{BB} , (b) the ground thickness t , (c) the length of the monopole antenna L_M .

A parametric analysis was accomplished to attain the optimum performance of the antenna. In this parametric analysis, the effect on S_{11} has been investigated at frequency 2.4 GHz. The ground thickness t was varied from 2 mm to 5 mm by a constant increment of 1 mm. Fig. 2 (b) illustrates the effects in S_{11} when t is varied. It is clearly seen that the resonant frequency is slightly shifted to this parameters. The optimum result for S_{11} at frequency 2.4 GHz is when t is equal to 3 mm.

Figure 2(c) shows the effect of the length of the monopole antenna L_M on the return loss and resonant frequency. As depicted in Fig. 2(c), it clearly shows that the length of the monopole antenna L_M has a significant effect on the return loss and resonant frequency. From the result in Fig. 2(c), $L_M=35$ mm is chosen so that the antenna is expected to operate at frequency 2.4 GHz.

4. Results and Discussion

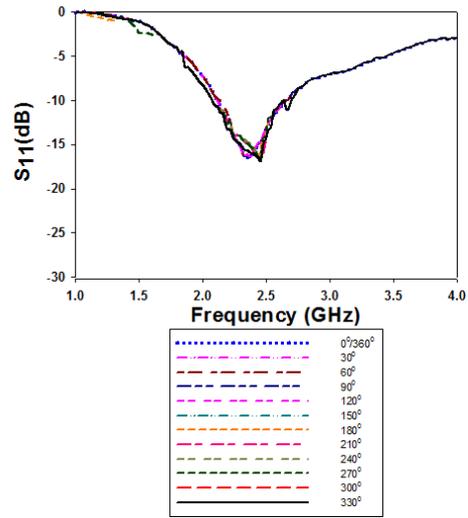
The prototype of reconfigurable plasma antenna array has been successfully fabricated and measured in order to validate the simulated results. Figure 1(d) shows the photograph of the fabricated antenna prototype.

Figure 3 (a) and (b) show the comparison between simulation and measurement results of S_{11} when the reconfigurable plasma antenna array is operating at 12 different numbers of sequences at frequency 2.4 GHz. It can be seen that very good agreement was obtained for all number of sequence, with the measured return loss lower than -10 dB. The results of the simulation seem to agree well with the measurement results. It is proven that the reconfigurable plasma antenna array can be operated at 2.4 GHz.

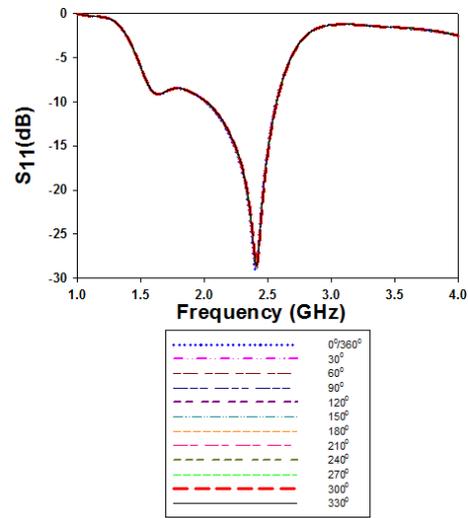
Generally, a number of activated elements (switched ON) will define the size of plasma window thus controlling the beam direction. In this investigation, with the optimized reconfigurable plasma antenna array, there are only 7 elements activated (switch ON) at the same time while 5 elements deactivated (switch OFF). Figure 4 shows the switching numbering for reconfigurable plasma antenna array. Table 2 shows the configuration of the reconfigurable plasma antenna array based on configuration in Fig. 4.

Beam Direction	Activated elements (Switch ON)	Deactivated elements (Switched OFF)
0°	3,4,5,6,7,8,9	10,11,12,1,2
30°	2,3,4,5,6,7,8	9,10,11,12,1
60°	1,2,3,4,5,6,7	8,9,10,11,12
90°	12,1,2,3,4,5,6	7,8,9,10,11
120°	11,12,1,2,3,4,5	6,7,8,9,10
150°	10,11,12,1,2,3,4	5,6,7,8,9
180°	9,10,11,12,1,2,3	4,5,6,7,8
210°	8,9,10,11,12,1,2	3,4,5,6,7
240°	7,8,9,10,11,12,1	2,3,4,5,6
270°	6,7,8,9,10,11,12	1,2,3,4,5
300°	5,6,7,8,9,10,11	12,1,2,3,4
330°	4,5,6,7,8,9,10	11,12,1,2,3

Tab. 2. Switching setting for the reconfigurable plasma antenna array.



(a)



(b)

Fig. 3. Reflection coefficient S_{11} : (a) Measurement, (b) Simulation.

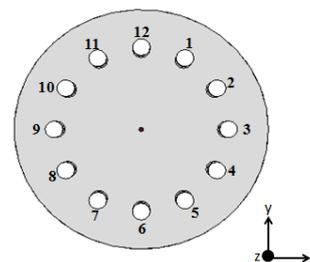


Fig. 4. Switching numbering for the reconfigurable plasma antenna array.

Figure 5(a)-(l) exhibit the simulated and measured radiation pattern in polar plot in H-plane at frequency 2.4 GHz. The results clearly show that the reconfigurable plasma antenna array could be pointed with twelve different steerable beam directions at each frequency mode, 2.4 GHz (0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, and 330°). The results of the simulation seem to agree well with the measurement results.

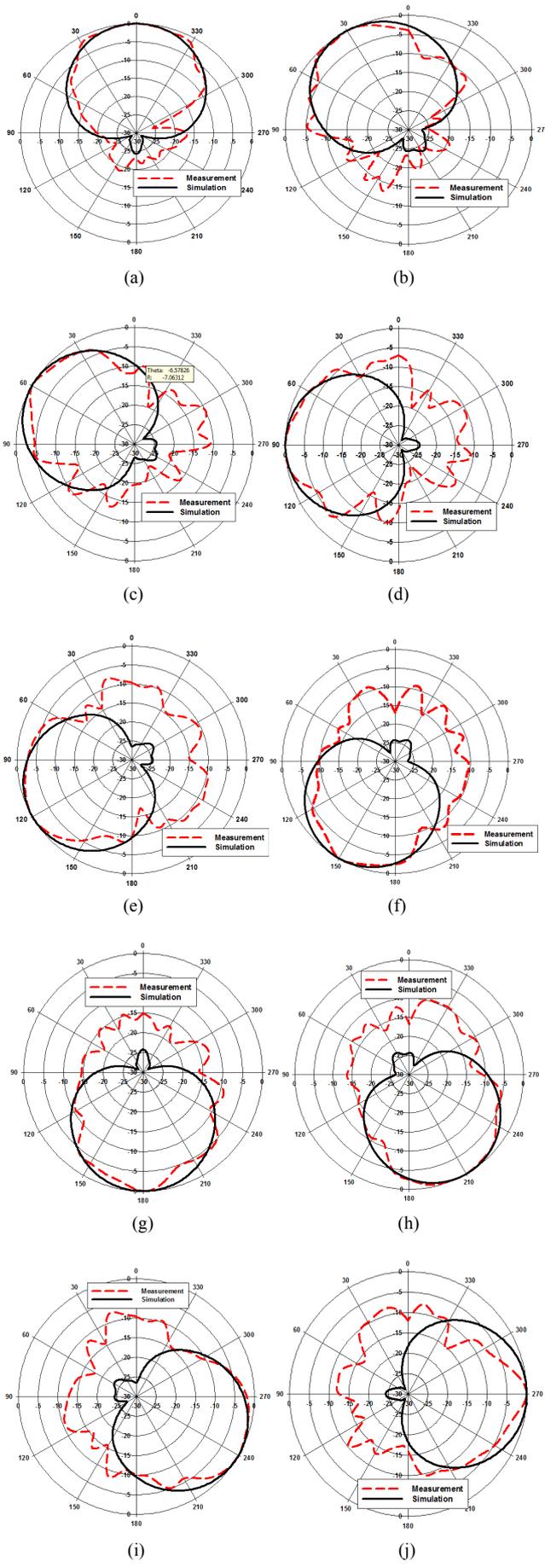


Fig. 5. Simulated and measured radiation pattern in H-plane at frequency 2.4 GHz at angle (a) 0°, (b) 30°, (c) 60°, (d) 90°, (e) 120°, (f) 150°, (g) 180°, (h) 210°, (i) 240°, (j) 270°, (k) 300°, and (l) 330°.

5. Conclusions

In this paper, the innovative design of a reconfigurable plasma antenna array has been described. The design of the antenna emphasizes on using plasma elements as the reflector elements instead of using metal elements. The plasma antenna of beam-switching is investigated based upon the interaction of plasma elements due to the incident electromagnetic wave. The simulated and measured data for the concept of the reconfigurable plasma antenna array that could produce steering beam pattern characteristics have been presented in this paper. This paper also includes a comparative analysis on the effects of several antenna parameters. Good agreement has been achieved between simulation and measurement results. The results confirm that the antennas could be steered in twelve directions, 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°, respectively at frequencies across the entire 2.4 GHz band, with excellent transmission matching for all configuration modes. Antenna designs with varied radiation patterns have great potential for wireless communication systems, such as for point-to-point applications.

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