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# Reconfigurable Patch Antenna Radiations Using Plasma Faraday Shield Effect

Oumar Alassane Barro, Mohamed Himdi, and Olivier Lafond, *Member, IEEE*

**Abstract**—This letter presents a new reconfigurable antenna associated with a plasma Faraday shield effect. The Faraday shield effect is realized by using a fluorescent lamp. A patch antenna operating at 2.45 GHz is placed inside the lamp. The performance of the reconfigurable system is observed in terms of  $S_{11}$ , gain and radiation patterns by simulation and measurement. It is shown that by switching ON the fluorescent lamp, the gain of the antenna decreases and the antenna system (patch+lamp) keeps a good matching at the operating frequency. This reconfigurable antenna can be used to avoid coupling with other communications or radar systems working in the same frequency band.

**Index Terms**—Patch antenna, reconfigurable plasma Faraday shield effect.

## I. INTRODUCTION

PLASMA is the fourth state of the matter with complex permittivity that can be exploited as a metal. When the plasma inside a container (tube in our case) is energized (state ON), the media performs like a conductive element capable to reflect radio signal like a metal [1], [2]. But, when the tube is de-energized (state OFF), the plasma is non-conductor and transparent to electromagnetic radiations. The main advantage of plasma reflector or plasma antenna compared to metallic element resides in the possibility to use an electrical control rather than a mechanical one. In [3], [4], the authors proposed plasma reflector antenna in order to steer the beam in certain directions. More recently, reconfigurable reflector plasma antennas have been realized by using low cost commercial fluorescent lamps (CFL), refer [5], [6]. On the other hand, a monopole fluorescent tube antenna was proposed in [7], [8].

In this letter, we present a reconfigurable patch antenna using a plasma Faraday shield effect. In reality, a Faraday cage is an enclosure formed by conductive material or by a mesh of such material. In our case, the Faraday shield is made with a fluorescent lamp which allows to obtain a reconfigurable gain and radiation pattern of a printed antenna by switching ON or OFF the plasma.

The paper is organized as follows: We present the plasma model in section II. In section III, we describe the modeling and simulation of the antenna system. The comparison between simulations and measurements is presented in section IV. A conclusion is given in section V.

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## II. DRUDE MODEL OF PLASMA MEDIUM

The behavior of the plasma is defined by the Drude dispersion model. The expression of the permittivity under low electron-neutral collision is given below (Eq. (1)).

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

where  $\epsilon_r$  is the complex plasma permittivity,  $\omega$  is the operating angular frequency, and  $\nu$  is the electron-neutral collision frequency.  $\omega_p$  is the plasma angular frequency and it is proportional to the density of unbound electrons or the amount of ionization in the plasma. The plasma angular frequency is defined as:

$$\omega_p = \sqrt{\frac{ne^2}{m\epsilon_0}} \quad (2)$$

where  $n$  is the electron density,  $e$  is the charge of electron,  $m$  is the electron mass, and  $\epsilon_0$  is the free space permittivity. When the operating angular frequency is greater than the plasma angular frequency ( $\omega > \omega_p$ ), the plasma acts like a classical dielectric medium and when the opposite is true ( $\omega < \omega_p$ ), i.e.  $\epsilon_r < 0$ , plasma acts like a metal. Consequently, depending on the angular frequency, the plasma can transmit or reflect the microwave radiation.

## III. MODELING AND SIMULATIONS

We design a circular patch antenna operating at 2.45 GHz which will be enclosed in CFL, used as Faraday shield effect. The geometry of the proposed patch antenna fed by a coaxial line is shown in Figure 1(a). This circular patch with a 31 mm diameter is printed on FR4 substrate with a thickness  $h = 3.2$  mm,  $\epsilon_r = 4.4$  and  $\tan \delta = 0.025$ . The diameter of the substrate is 50 mm. The feed point is located along the  $y$ -axis, at a distance  $d = 5$  mm from the center of the patch. The antenna is polarized along the  $y$ -axis and the ground plane is on the bottom of the substrate.

The geometry of the spiral-shaped lamp [9] is shown in Figure 1(b) and Figure 2. The height of the lamp is 134 mm, the inner diameter is 60 mm, the spiral diameter is 19 mm, the outer diameter is 98 mm, and the gap between the turns is 3.64 mm. A ground plane size of  $200 \times 200$  mm<sup>2</sup> is used in the bottom of the lamp in order to mask the electronic devices used to energize the plasma. The patch antenna is put inside the lamp at a height equals to 50 mm from the ground plane. The realized prototypes and measurement setup are shown in Figure 2.

In simulation (performed using CST Microwave studio [10]), the tubes containing the gas are made from lossy glass Pyrex with  $\epsilon_r = 4.82$ ,  $\tan \delta = 0.005$  and thickness of 0.5

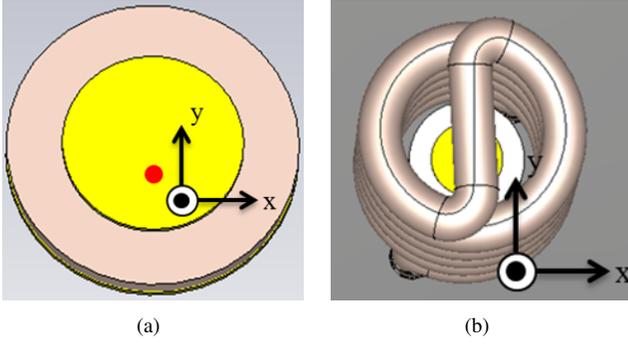


Fig. 1. Simulated models. (a) The patch geometry. (b) The fluorescent lamp geometry.

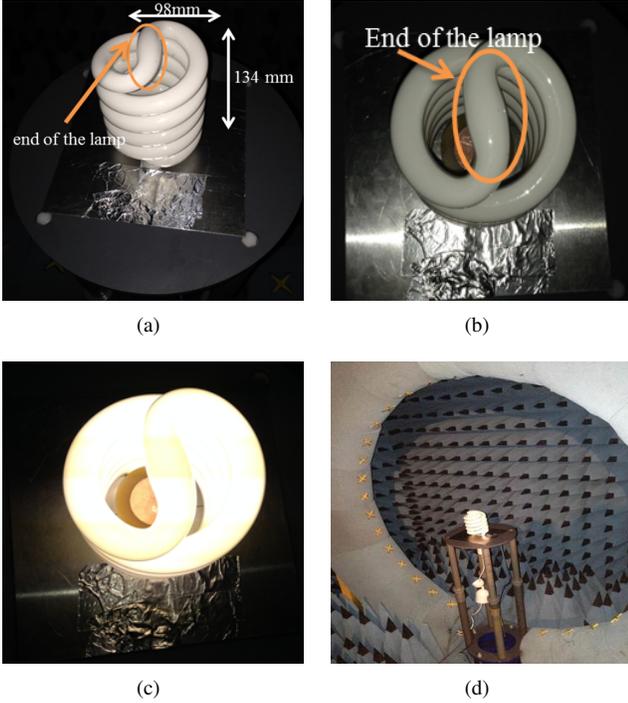


Fig. 2. Realized models. (a) The Faraday shield. (b) Plasma OFF. (c) Plasma ON. (d) Radiation pattern measurement setup (SATIMO).

mm. The plasma obeys to the Drude model. At the beginning, we used the same Drude model as in [5], with the same parameters ( $\nu = 900$  MHz and  $\omega_p = 43.9823 \cdot 10^9$  rad/s). Unfortunately, the simulation results were not in good agreement with measurements. Hence, we tried to match the simulations with the measurement by changing the plasma parameters defined in the Drude model. After retro-simulations,  $\omega_p = 62.8318 \cdot 10^9$  rad/s is considered and  $\nu$  is kept equal to 900 MHz. In the absence of information from the manufacturer, the retro-simulation was necessary in order to have realistic plasma data for this kind of lamp.

#### IV. RESULTS AND DISCUSSION

The results are separated in two cases in order to understand the interaction between the patch antenna and the lamp. In the first one, the electric field polarization is parallel to the end

of the lamp ( $y$ -axis), while in the second one the electric field polarization is orthogonal to the end of the lamp ( $x$ -axis).

The simulated and measured  $S_{11}$  parameters are shown in Figure 3 for the patch alone and by switching ON or OFF the fluorescent lamp (Plasma ON / Plasma OFF). The measured results are in a good agreement with the simulated ones. For all configurations (patch alone, plasma OFF, plasma ON), the resonant frequency is close to 2.45 GHz in both simulation and measurement (Fig. 3(a) and 3(b)). The Figure 3(a) shows also the magnitude  $S_{11}$  parameter when the plasma is replaced by a lamp made of perfect electrical conductor (PEC). It is important to notice that the antenna system (patch + PEC) is not well matching at the operating frequency ( $-2.89$  dB at 2.45 GHz). On the contrary, with the plasma lamp, the results show that the matching of the patch is not significantly affected by the plasma (ON or OFF). The  $S_{11}$  parameters are the same in both polarization cases.

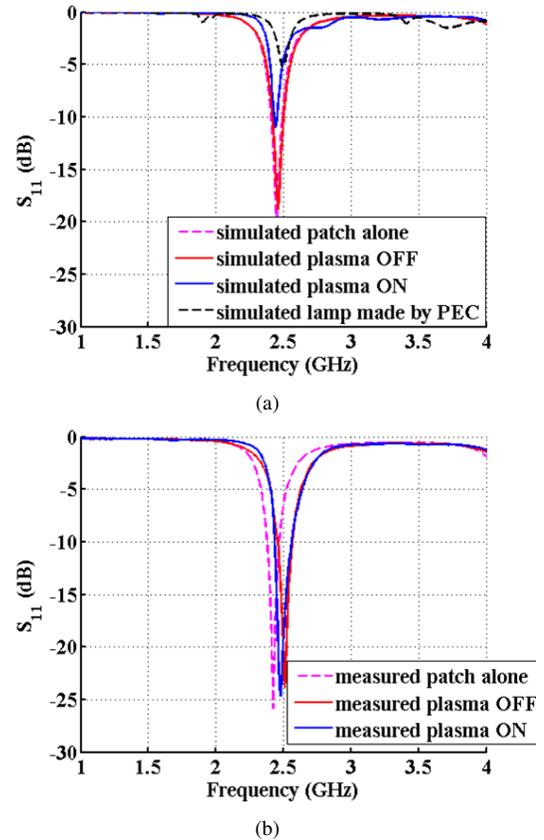


Fig. 3.  $S_{11}$  magnitude comparison. (a) Simulation. (b) Measurement.

Radiation patterns have been measured in order to validate the simulation results. Measurements have been performed in a SATIMO anechoic chamber (near fields setup) with a peak gain accuracy equals to  $\pm 0.8$  dBi. The measurement setup with lamp, used as Faraday shield effect, is shown in the Figure 2(d). The Figures 4 and 6 show the measured and simulated radiation patterns at 2.45 GHz, for respectively the co- and the cross-polarization. For both simulation and measurement results, each radiation pattern is normalized to the maximum value of the electric-field for the plasma

OFF. We can clearly observe that the radiation patterns in measurement and simulation are similar.

- First case: Regarding the gain, we can notice a difference of 12 dB for both simulation and measurement between plasma OFF and plasma ON for  $\theta = 0$  in co-polarization (Fig. 4(a) and 4(b)) and a difference of 5 dB for the measured cross-polarization ( Fig. 4(c) and 4(d)). In co-polarization, the antenna gain decreases strongly when the plasma is ON. In order to understand well the effect of the plasma, the Figure 5 shows the normalized co-polarization radiation patterns when the plasma is replaced by a PEC and for the two principal planes (E and H). The difference of gain between plasma OFF and metal at  $\theta = 0$  is 15 dB. This result shows that the PEC is more efficient for shielding but as seeing in Figure 3, the using of plasma lamp allows to keep a good matching for the antenna at the operating frequency and their radiation patterns are also reconfigurable.
- Second case: The difference of gain is 7 dB in simulation and 5 dB in measurement at  $\theta = 0$  between plasma OFF and plasma ON in co-polarization (Fig. 6(a) and 6(b)) and almost 15 dB for the measured cross-polarization (Fig. 6(c) and 6(d)).

In the Figures 4(c), 4(d), 6(c) and 6(d) the level of simulated plasma OFF cross-polarization are very low in E and H-planes and do not appear in the figures.

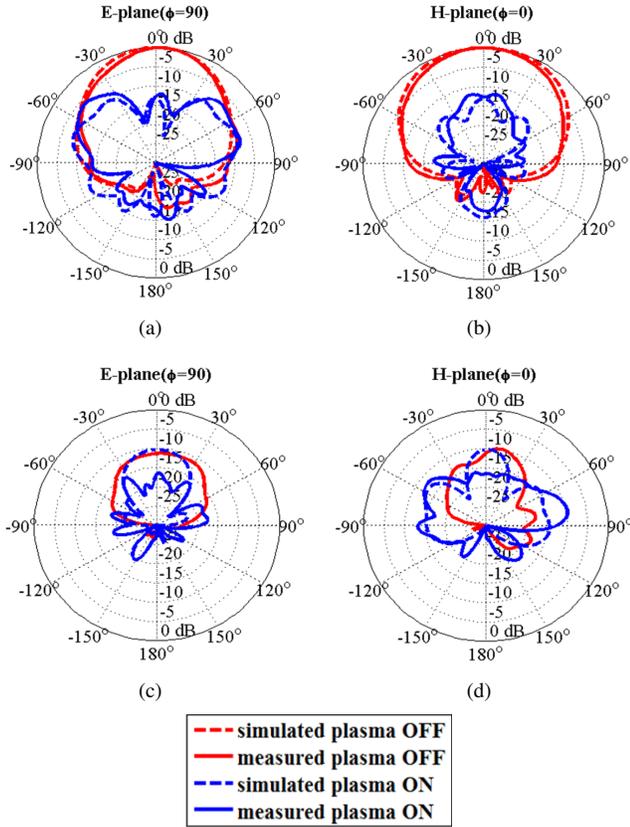


Fig. 4. Normalized radiation patterns at 2.45 GHz for plasma OFF and plasma ON in the first case. (a) Co-polarization E-plane. (b) Co-polarization H-plane. (c) Cross-polarization E-plane. (d) Cross-polarization H-plane.

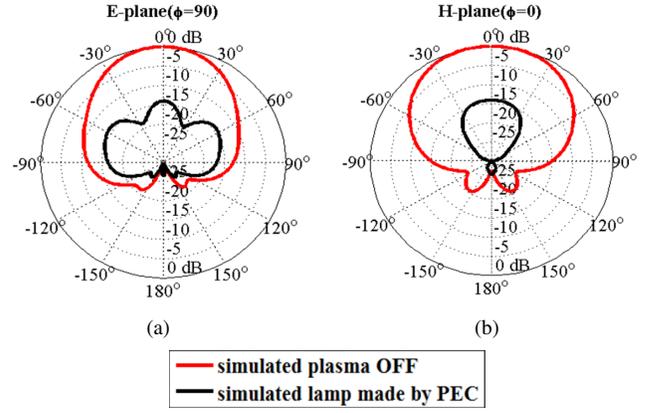


Fig. 5. Normalized radiation patterns at 2.45 GHz for plasma OFF and plasma replaced by metal. (a) Co-polarization E-plane. (b) Co-polarization H-plane.

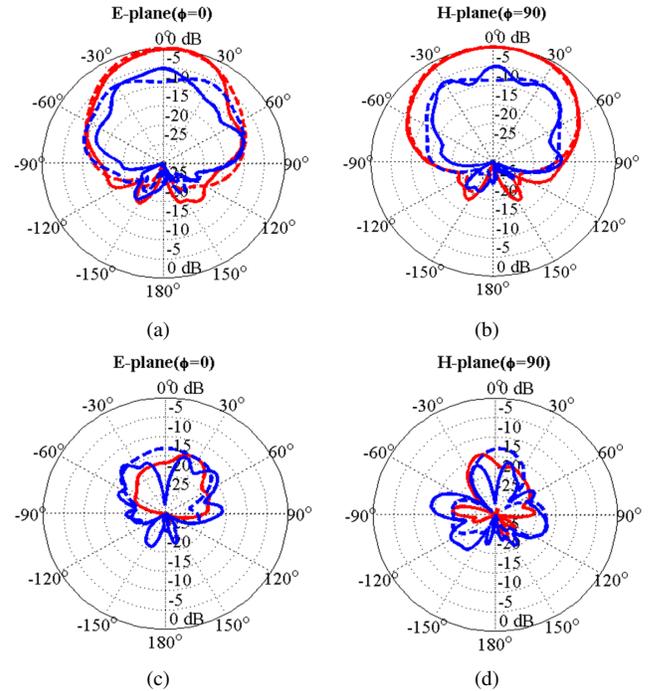


Fig. 6. Normalized radiation patterns at 2.45 GHz for plasma OFF and plasma ON in the second case. (a) Co-polarization E-plane. (b) Co-polarization H-plane. (c) Cross-polarization E-plane. (d) Cross-polarization H-plane.

In both cases, the measurements of cross-polarization give the expected results but the simulation results show the opposite behavior due to the non-perfect model.

The results obtained for the first case (polarization of patch along y axis) are more interesting because the decreasing of gain is more significant.

After, we tried to find which part of the lamp affects the radiation patterns. Thus, in the simulations (first case), the lamp is separated in two parts, the end of the lamp (without spiral part) and the spiral part (without the end of the lamp).

Figure 7 shows the co-polarization radiation patterns in E-plane (Fig. 7(a)) and H-plane (Fig. 7(b)) of the end of the lamp and spiral part compared to the plasma OFF and plasma ON. We notice that, the radiation patterns are affected by the combination of both parts and not only by the end of the lamp. In fact, the lamp and the patch are relatively near to each other, so the impact of lamp must be seen in near fields conditions that can explain why the two apmts of the lamp (end and spiral ones) affect the electric field of the patch antenna.

Table I and Table II present respectively the maximum simulated and measured gain at 2.45 GHz for both polarization cases. From these results, it is very interesting to notice that the radiation of the patch can be strongly reduced when the plasma is ON. This means that the lamp acts like a Faraday shield effect.

TABLE I  
REALIZED GAIN MAX IN THE FIRST CASE

States	Plasma OFF	Plasma ON
Maximum simulated gain (dBi)	6.4	0.3
Maximum measured gain (dBi)	5.5	-0.7

TABLE II  
REALIZED GAIN MAX IN THE SECOND CASE

States	Plasma OFF	Plasma ON
Maximum simulated gain (dBi)	6.4	1.4
Maximum measured gain (dBi)	5.4	0.2

## V. CONCLUSION

In this letter, a Faraday shield effect using commercial Fluorescent Lamp (plasma) was presented. Two cases have been simulated and measured showing the impact of the lamp on the gain of patch antenna put inside it. By switching OFF or ON the plasma, the lamp behaves like a transparent media or a Faraday shield effect respectively and the  $S_{11}$  parameters keep a good matching at the operating frequency. This reconfigurability could be used to reduce antenna gain when different communication systems, working at the same frequency, are put close to each others. Moreover, the Faraday shield can be used to protect antenna from external high power aggression.

## ACKNOWLEDGMENT

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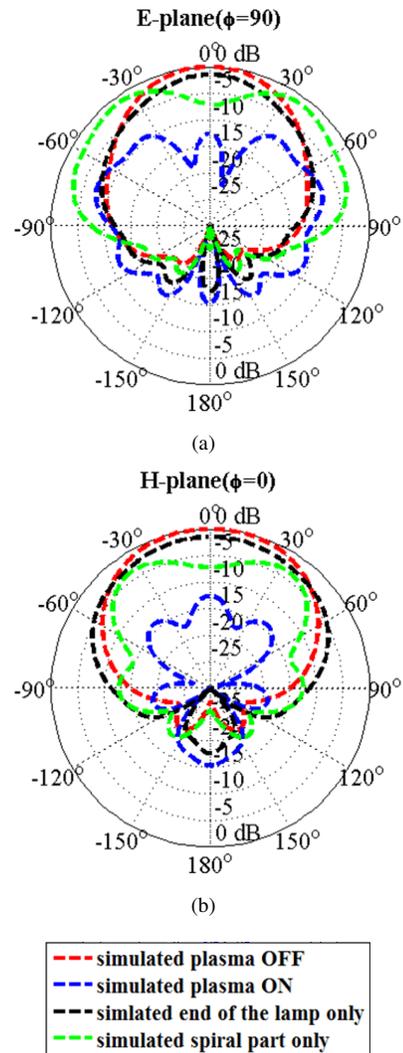


Fig. 7. Normalized radiation patterns at 2.45 GHz for plasma OFF, plasma ON, the end of the lamp and spiral part. (a) Co-polarization E-plane. (b) Co-polarization H-plane.

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