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Reconfigurable slotted cylindrical waveguide and coaxial array antenna using plasma

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***Abstract*—A novel reconfigurable cylindrical slotted waveguide antenna associated with plasma tube is proposed. The performance of the reconfigurable system is observed in terms of S_{21}, maximum realized gain, radiation patterns and total efficiency. It is shown that by switching ON or OFF the fluorescent lamp, we can change the antenna operating mode. When the plasma is OFF, we have the waveguide behavior with a cutoff frequency around 2.5 GHz and when the plasma is ON, the behavior become 50 Ω coaxial line. By adding slots, we obtain reconfigurable antenna working at 4 GHz and 1 GHz. The main idea is to obtain reconfigurable slotted cylindrical waveguide and coaxial array antenna using plasma**

***Index Terms*—slot waveguide antenna, coaxial line, reconfigurability, plasma**

I. INTRODUCTION

Since many years, slotted waveguide antennas have been studied in the literature [1]–[7]. Many papers [8]–[12] proposed a waveguide filled by plasma in order to change the mode or as a protection against the high power. In our case, the waveguide is filled by plasma partially. The aim of this paper is to present simulation and experimental results to verify the performance in terms of radiation pattern, gain, S-parameters and efficiency of the reconfigurabe slotted waveguide antenna using plamsa tube. Two operating modes are offered by this antenna system depending the state of the plasma. Two behaviors can be also indentified, a waveguide behavior when the plasma is OFF and a coaxial behavior when the plasma is ON. The paper is organized as follows: in section II, we describe the prototype and remind the used plasma model. The comparison between simulations and measurements of the metallic cylindrical tube filled by plasma is presented in section III. The Results for slot waveguide and coaxial antenna are presented in Section IV. A conclusion is given in section V.

II. MODELING AND SIMULATIONS

The waveguide geometry is shown in Figure 1. The metallic tube has 70 mm diameter and the length is 620 mm. The plasma tube which is commercial fluorescent lamp is inserted inside the metallic tube (see Figs. 2(a) and 2(b)).

The height of the lamp is 590 mm and its diameter is 26 mm. The feeding system is composed by a metallic ring surrounding the lamp to its end and a coaxial cable is fixed to this metallic ring (see Fig. 2(b)) in order to provide RF signal. The realized prototype are shown in Figure 2(b).

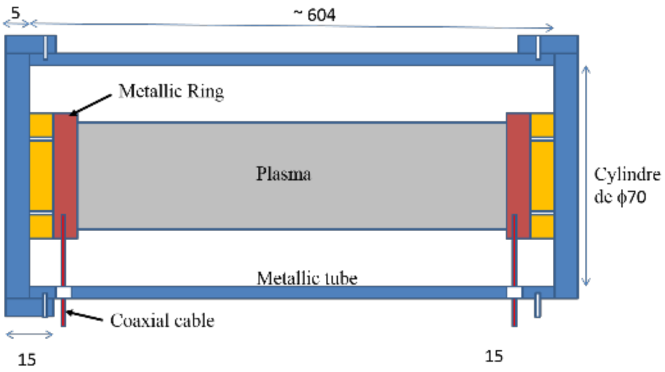


Fig. 1. Geometry of the system.

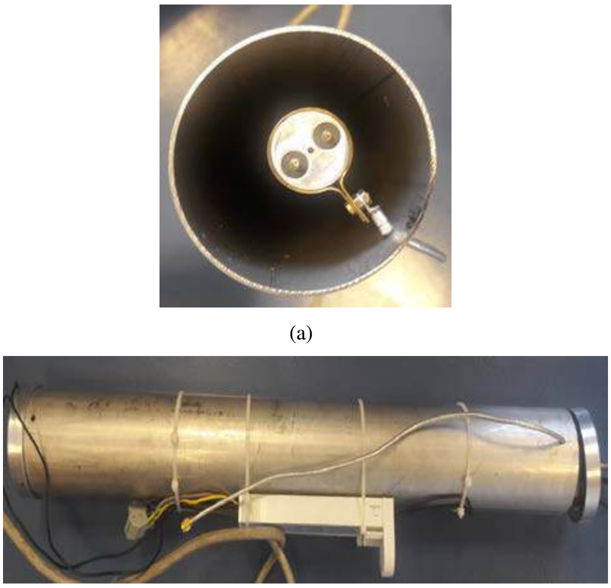
For simulations performed with CST Microwave Studio, the tube containing the gas is made from loss glass with $\epsilon_r = 4.82$, $\tan\delta = 0.005$ and thickness of 0.5 mm. The plasma obeys to the Drude model defined by the two parameters (plasma angular frequency ω_p and electron-neutral collision frequency ν) and these parameters give the complex permittivity ϵ_r written in equation (1).

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

where ω is the operating angular frequency.
Furthermore, we used the same Drude model as in [13]–[15], with the same parameters ($\nu = 900$ MHz and $\omega_p = 43.9823\ 10^9$ rad/s).

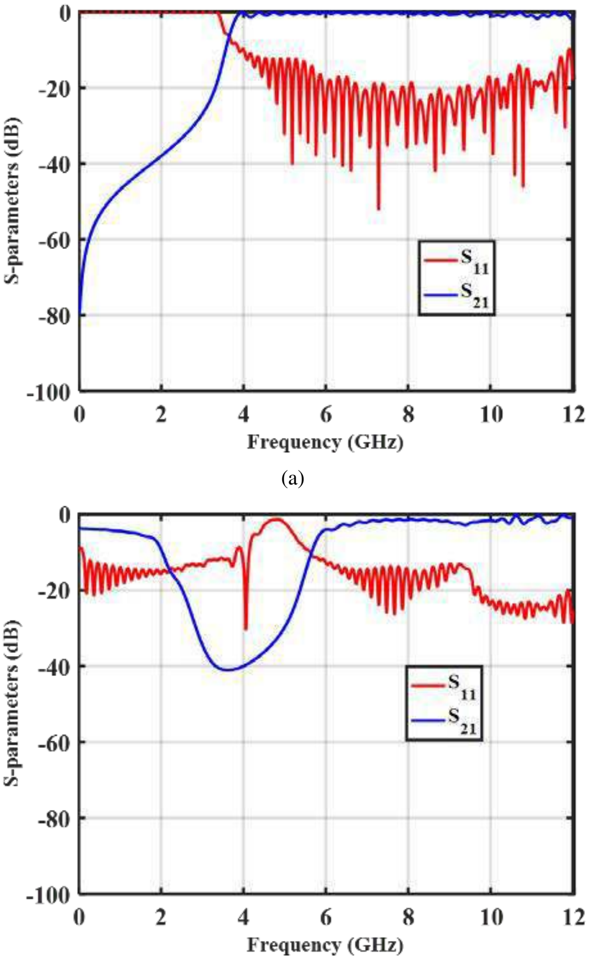
III. RESULTS AND DISCUSSION

First, we start to study the S parameters in order to find the behavior of the metal tube depending on the state of the plasma. Figure 3 shows S_{11} and S_{21} magnitude results in simulation in the cases plasma OFF and plasma ON.


(a)

(b)

Fig. 2. Realized models. (a) Feeding lamp. (b) Realized waveguide.



(a)

(b)

Fig. 3. Simulated S_{11} and S_{21} magnitude. (a) Plasma OFF. (b) Plasma ON.

We can notice that, in the plasma OFF case, we have expected results for a classical waveguide with a cutoff frequency around 2.5 GHz (see Fig. 3(a)). The Figure 3(b) shows the result in plasma ON case, we obtained the expected results for a coaxial but the stronger absorption is observed arrond 4 GHz. In order to valide the simulations results, the S_{21} measurements have been done in the plasma ON and OFF cases and shown in Figure 4. The simulations and measurements are in good agreement but we have more losses in measurement and the curve in plasma OFF shows a rise in low frequency, probably due to the prototype fabrication and feeding system.

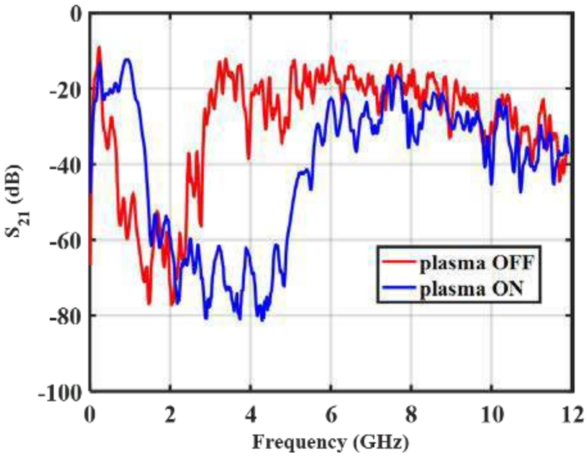


Fig. 4. Measured S_{21} magnitude in plasma OFF and ON cases.

IV. RESULTS FOR SLOTTED WAVEGUIDE AND COAXIAL ANTENNA

Now, in order to use the metallic tube as antenna, we add 12 small slots ($ls = 40\ mm$, $ws = 5\ mm$) as presented in Figure 5 and the distance inter slot is $\lambda/2$ at 4 GHz (40 mm) in order that antenna radiates at 4 GHz in plasma OFF case. Furthermore, 4 big slots ($ls = 150\ mm$, $ws = 5\ mm$) and distance inter slot equal to $\lambda/2$ at 1 GHz (150 mm) are added. The antenna operate at 1 GHz in plasma ON.

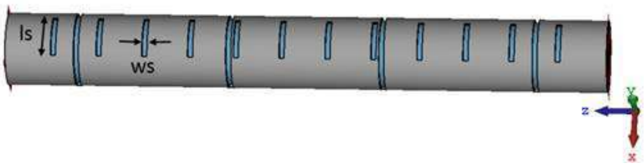
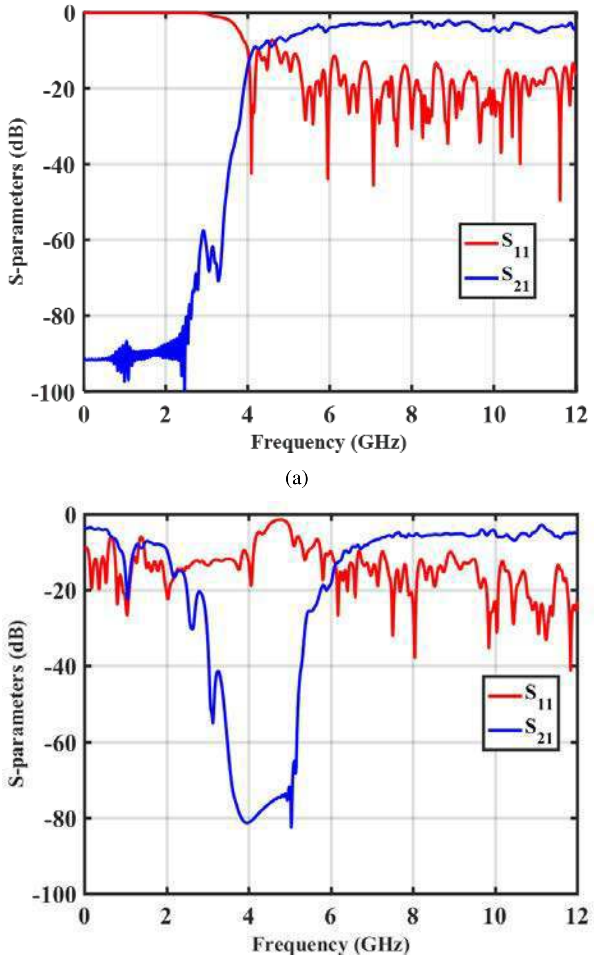


Fig. 5. Geometry of the slotted waveguide, small slots ($ls = 40\ mm$, $ws = 5\ mm$) for 4 GHz antenna and big slots ($ls = 150\ mm$, $ws = 5\ mm$) for 1 GHz antenna.

The Figure 6 shows S_{11} and S_{21} of the antenna with slots in plasma OFF (Fig. 6(a)) and ON (Fig. 6(b)) cases. The matching around 4 GHz is -40 dB and the S_{21} is -10 dB, that mean, most of the energy is radiated, given good gain and good efficiency. Turned the plasma ON, due the transformation from waveguide to coaxial line, the matching at 1 GHz becomes -20 dB and S_{21} is around -20 dB. In this case, we succeed to have a good gain and good efficiency for array with 4 elements.



(a)

(b)

Fig. 6. Simulated S_{11} and S_{21} magnitude of the slotted antenna. (a) Plasma OFF. (b) Plasma ON.

Radiation patterns have been presented in Figure 7 in order to demonstrate the reconfigurable capability of this antenna system.

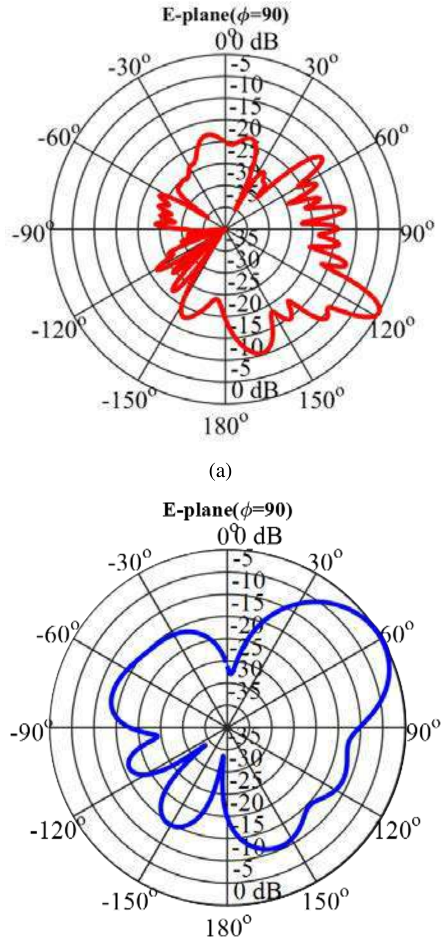
The Figures 7(a) and 7(b) shows the E-plane simulated radiation patterns respectively for the frequencies 4 GHz in plasma OFF case and 1 GHz in plasma ON case. For both simulation results, each radiation pattern is normalized to the maximum value of its electric-field.

The simulated -3 dB beamwidth is $8.1°$ at 4 GHz and $34.1°$ at 1 GHz. The antenna is tilted in both frequencies, $120°$ at 4 GHZ and $60°$ at 1 GHz. The side lobe levels (SLL) are around -10 dB whatever the configurations.

The simulated maximum realized gain are shown in Figure 8. In the plasma OFF case, the gain is maximum at 4 GHz and equals to 13.27 dBi. In ON case, the gain is maximum at 1 GHz and equals to 6.82 dBi. Regarding the gain, we can notice a difference of 40 dB at 1 GHz between plasma OFF and plasma ON and a difference of 52 dB at 4 GHz between plasma OFF and plasma ON.

Normally, the antenna should not work at 1 GHz because the cutoff frequency is higher than 1 GHz, but when the lamp is turned ON the waveguide becomes a coaxial line from where to get the radiation pattern and gain at 1 GHz.

From the gain, the efficiency of the antenna is evaluated. The total efficiency is 83.4% at 4 GHz (plasma OFF) and 68.2% at 1 GHz (plasma ON).



(a)

(b)

Fig. 7. Normalized H-plane radiation patterns. (a) 4 GHz in plasma OFF. (b) 1 GHz in plasma ON.

V. CONCLUSION

In this letter, a reconfigurable slotted antenna using plasma tube inside the mettalic waveguide and allowing to obtain a reconfigurable radiation patterns according to the state of plasma was presented. The radiation patterns at 4 GHz and 1 GHz have been given showing the impact of the plasma tube. The main advantage of this antenna when the plasma is ON, is to have the possibility to radiate at 1 GHz, and

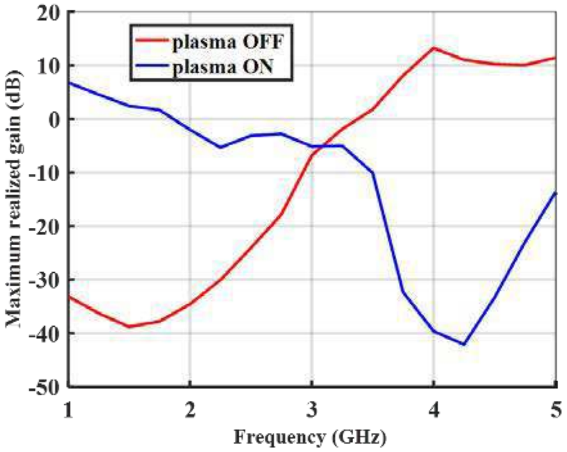


Fig. 8. Gain of the antenna in plasma OFF and ON cases.

in the same time to have a strong reduction of the gain at 4 GHz allowing a good protection against high power aggression radar or communication systems working at this frequency.

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