# Perfomance Analysis of the Loop-Shaped Plasma Antenna Under Different Pressure Conditions

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*Abstract*— **This study examines the effect of different pressures on the radiation characteristics of the loop-shaped plasma antenna filled by two gases; Argon and Nitrogen. Proposed loop plasma antennas operating at LTE and Wi-Fi frequency bands have been designed and its performance studied at three different pressures of 2.28, 5 and 10 Torr. The radiation characteristics of the both loop-shaped plasma antennas have been investigated and presented for three different pressures. To analyze the performance of the proposed antenna, full-wave simulation were run using the finite integral method software, CST Microwave Studio.**

***Keywords—Plasma ; loop antenna; pressure; radiation pattern; return loss***

## I. INTRODUCTION

Plasma medium is stated as the fourth state of the material, owing to its properties which are totally different from other states of medium (gaseous, liquid, and solid). Plasma medium is formed by ions and electrons where other states formed by atoms, Fig. 1. The name of "Plasma" was first presented in physics research in the early 1920s [1]. Prior to that, plasma was first invented as a radiator to transmit electromagnetic signals just after First World War. In 1919, the concept of plasma antenna was patented and the patent was awarded to J. Hettinger with the name of "Aerial Conductor for Wireless Signaling and Other Purposes" [2]. But even though plasma antenna had its beginnings in early 20 century, its considerable improvement started in 1960s when the plasma began to be introduced in communication systems [3]. Since then there is a significant amount of contraptions were made by many institutes and research groups to apply plasma as antenna [4-8]. Prevalent traditional antennas and other types of material based antenna such as dielectric resonators and metamaterials have been studied widely while there is the little study on plasma antennas [9-13]. It must be noted that most of the researches on plasma antenna parameters had done on the basic form of plasma antenna (plasma column) [14-18]. In [14] the return loss of a plasma monopole antenna with different radius and length are reported. The return loss of cylindrical plasma antenna with different electron density is simulated and investigated in [15]. Sharan Bonde and et al. studied plasma monopole antenna parameters with two different gases, argon and neon where radiation patterns and return losses of both structure were reported in [16]. In [17], Nur Aina Halili and et.al. presented three type of plasma antennas with different gases, xenon, argon, and neon, at the same pressure of 1 Torr while the RF heating method for ionization of the gas has been used. Nur Aina Halili and her colleagues investigated the performance of a plasma monopole antenna that is ionized based on RF charging at different circumstances and presented the return loss and radiation pattern [18]. These circumstances consist of a different figure of turns of coupling sleeve, various gases - argon, fluorescent, and nitrogen - four different pressure (0.5, 1, 5, and 10 Torr) only for one gas, argon.In [19] the effect of various types of gases, pressures and coupling sleeves on the efficiency of a monopole antenna has been studied and reported.

In this paper, for the first time, the performance of the loop-shaped plasma antenna filled by two different gases (Nitrogen and Argon) under three level of pressures have been studied and presented.

## II. BASIC THEORY AND PLASMA PARAMETER

Plasma is an ionized gas and in terms of electromagnetic properties is a non-liner, non-homogeneous and dispersive environment. Permittivity, permeability and conductivity in this medium can be varied in terms of frequency.

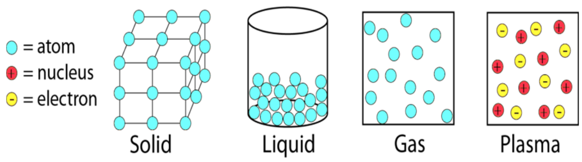


Fig. 1. Plasma and other state of matter

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The relative permittivity of plasma is [20]:

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

Where $\omega$ is operating frequency, $\omega_p$ is plasma frequency and $\vartheta$ is collision frequency that plasma frequency is defined by [17]:

$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m_e}} \qquad (2)$$

Where $n_e$electron density is the charge of electron and $m_e$ is the mass of electron.

## III. Plasma Antenna

In all type of antennas, there is a conducting part which is the fundamental element that guides and radiates the electromagnetic waves made by various materials. Plasma antenna is a kind of radio frequency antennas which applies to practice plasma as the radiation and guiding medium. Various types of plasma antennas have been designed and tested like monopole antenna, helical antenna [21]. But the design of the under test proposed loop-shaped antenna was first introduced by the authors of this paper [22]. These antennas have more degree of freedom than metal antennas that create huge possibility in their application, like using plasma medium as a microwave reflector in radar system [23-25]. Each plasma antenna consists of three main segments. First, the enclosure which plasma settles in it. The second segment is plasma as a conductor and the third segment is a coupler to receive and transmit signal.

## IV. Simulated results and discussion

For simulating a loop plasma antenna, we should design three separate stages. The first one is the design of an enclosure that ionized gas can settle in it. Most of the researches have been done on the basic form of plasma antenna like plasma column [26-30]. In this paper, a loop-shaped of plasma antenna with the dimension of commercial florescent tube (T9) with regard to [22] is simulated as an enclosure, Fig.2. Simulating the plasma medium is the next step. In this work two loop plasma antennas with various gases (Ar, N) at three different pressures (2.28, 5, 10 Torr) are simulated by the Durd model of the Computer Simulation Technology, CST 2017, [30].

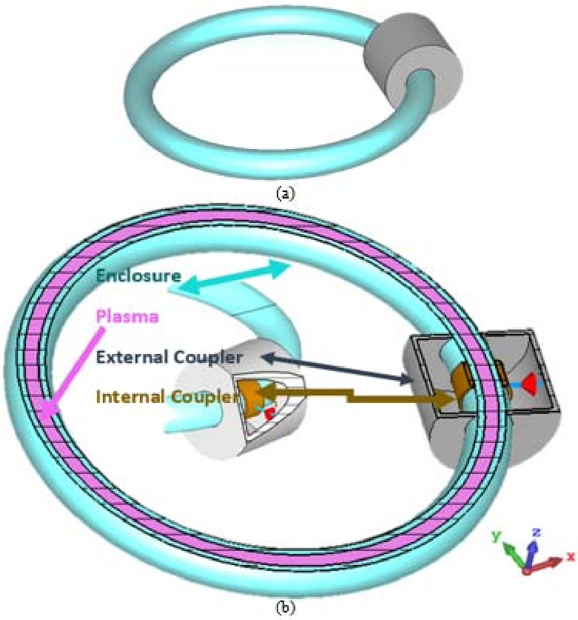


Fig. 2. Loop plasma antenna (a) side view (b) cross section view and detailed of couplers.

In this model, the behavior of plasma and the effect of electron collision is associated. This model is developed to represent the commercially available plasma source used in the experimental activities [30].The final step is to simulate a coupler which regards to [20] it should consist of two parts, internal and external coupler, Fig.2-b and the simulated return loss results of the plasma antenna with Ar gas and N gas at pressure 2.28, 5, and 10 Torr is shown in Fig.3 and Fig. 4, respectively.

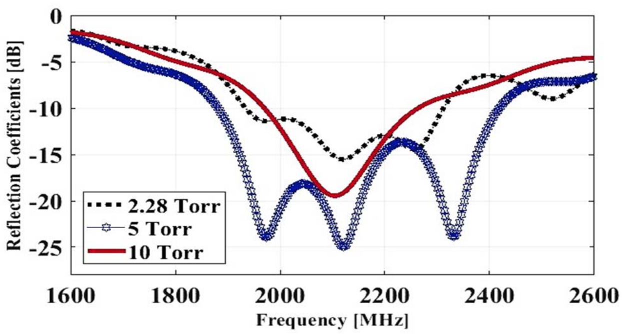


Fig.3 Simulated reflection coefficient plot of Ar loop plasma antenna at 2.28Torr, 5Torr and 10 Torr.

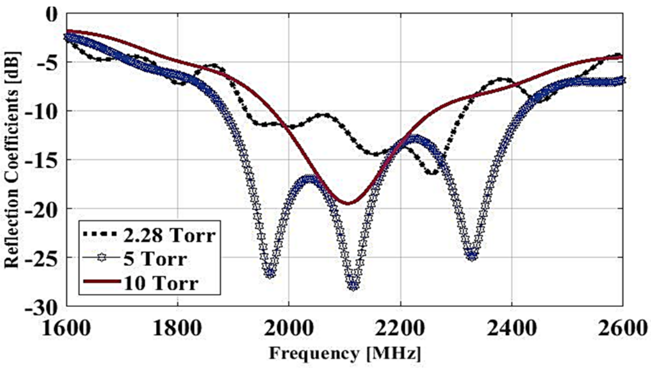


Fig.4 Simulated reflection coefficient plot of N loop plasma antenna at 2.28 Torr, 5 Torr and 10 Torr.

The functional antenna in term of return loss has return loss values smaller than -10 dB. As can be clearly seen from Fig.3 and Fig.4 all of the plots of S11 parameters have values less than -10 dB and the results show that the increase of pressure leads to a shift at the resonant frequency. It is unworthy that changing the gas pressure, not only shifts the resonant frequency, it also enhances bandwidth range. Although the loop plasma with N gas has better matching compared to that of Ar gas, the best result of return loses belongs to the loop-shaped plasma antenna at the pressure of 5 Torr which has most bandwidth among other in both types of the antennas. The E-pattern of N and Ar loop-shaped plasma antenna is shown in Fig.5 and Fig.6 at three various pressures respectively.

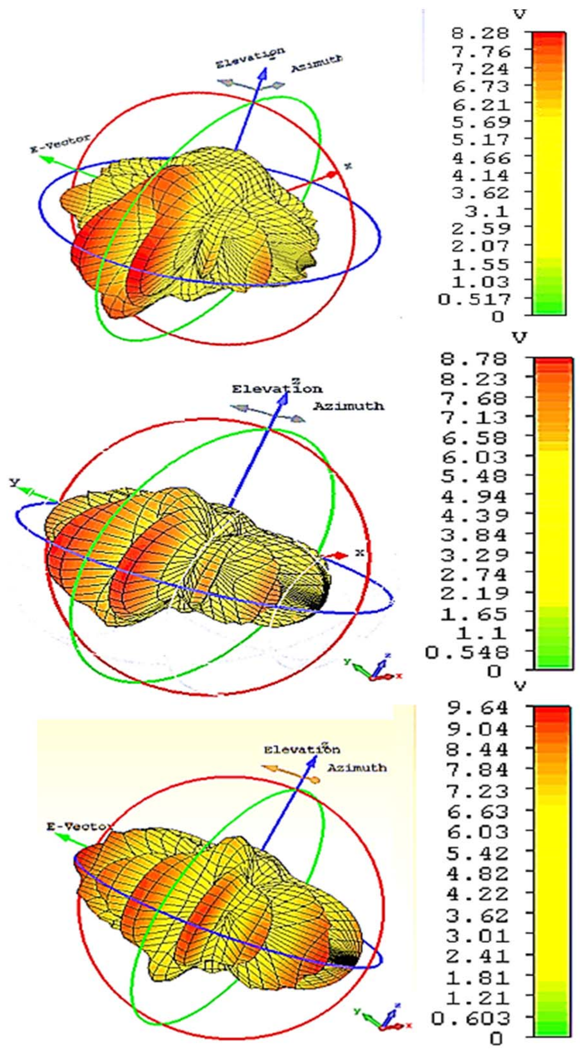


Fig. 5. E- Pattern of **N** loop plasma antenna at (a) 2.28Torr, (b) 5Torr and (c) 10 Torr.

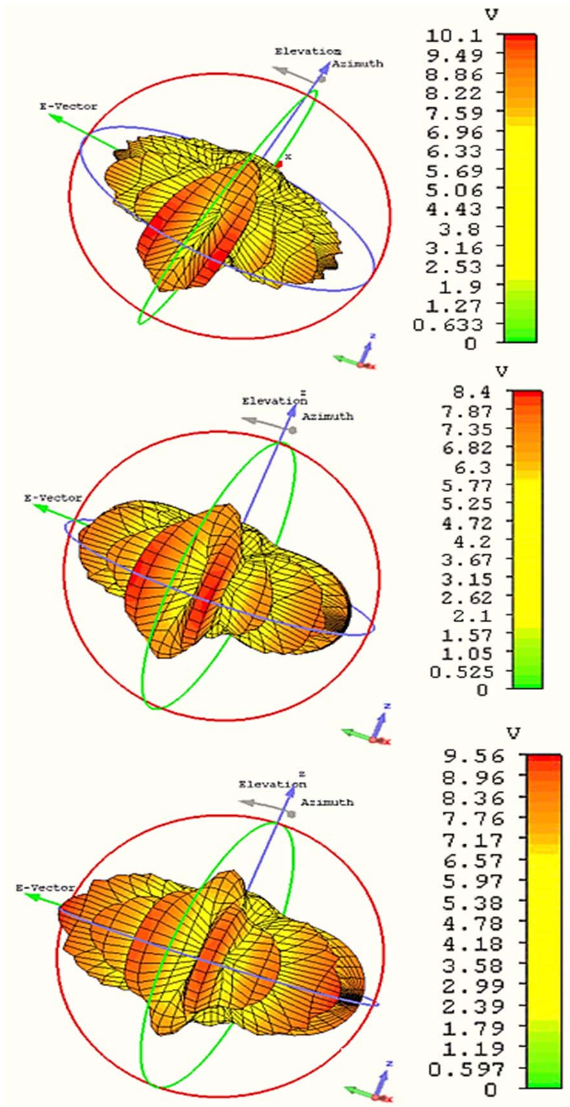


Fig. 6. E- Pattern of **Ar** loop plasma antenna at (a) 2.28Torr, (b) 5Torr and (c) 10 Torr.

As can be clearly seen from the results, loop plasma antenna with N gas is an easier gas and better choice compared to Ar gas owing to achieve better radiation features like impedance matching.

## V. CONCLUSION

In this paper, for the first time, radiation characteristics of the loop-shaped plasma antenna under different physical parameters have been investigated. It must be noted that the effect of different pressures of two loop-shaped plasma antennas filled by two gases (Ar, N) with the same dimension has been studied and the antennas' radiation characteristics such as return loss and radiation patterns were presented. It was observed that the reflection coefficient of both antennas by changing the pressure of the gas has been changed and made a shift in resonant frequency and the range of bandwidth. Proposed loop-shaped plasma antenna due to low weight, low mutual coupling and smaller in size are able to use instead of metal elements especially in space application owing to low weight. Also, the proposed antennas are a good candidate for LTE and UMTS.

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