Performance Analysis of Plasma Antenna with Different Shapes of Plasma Tube.

H Ja’afar¹*, NANM Khair² and AN Dagang²
¹Faculty of Electrical Engineering, University Teknologi MARA, Terengganu Branch, 23000 Dungun, Terengganu Malaysia.
²School of Ocean Engineering, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu.

hajarij422@uitm.edu.my

Abstract. This paper investigates analysis of a novel antenna design using plasma element instead of using metallic element as a conducting medium in transmit signal of radio frequency (RF). The main objective in this paper is to analyse the performance of plasma antenna using with different shapes of plasma tube. In this research, the simulation for four different designs (single tube, double tube, triple tube, and U-tube) with fixed gas (neon) and pressure (10 Torr) were conducted. Four different design tubes with constant length (160 mm) and diameter (10 mm), attached with coupling sleeve (copper) were used to analyze the electrical characteristic of electromagnetic wave propagation. Computer Simulation Technology (CST) was used to design the four custom made tubes and calculate the antenna parameters in terms of gain, return loss, directivity and radiation pattern. Plasma parameters were calculated by the CST software with frequency was set starting from 1 to 10 GHz for simulation based on the most effective range to get the best result. The results revealed that the triple tube has the highest gain of 3.247 dB with plasma frequency $1.22\times10^9$ rad/s and collision frequency $6.0985\times10^8$ collision/s. The three arrays on the triple tube gave the ability to transmit the input power into radiation in a specific magnitude is high. Although high gain obtained from the triple tube, U-tube shape gave the lowest Return Loss, $S_{11}$ value which is -15.706934 dB. The results show the ability of plasma antenna to transmit and receive a signal which is a basic part of an antenna.

1. Introduction

The usage of plasma as a conductive element in microwave devices has drawn growing interest due to their peculiar and innovative properties with respect to the traditional metallic circuits. At present, the industrial potential of plasma technology is well-known and has been excellently demonstrated in several processes of microwave technology, which incorporates the use of an ionized medium.

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 of solid to liquid to gas and plasma. Hence, it consists of positive (and negative) ions and electrons, as well as neutral species. The formation of plasma is start from when a solid is heated sufficiently until the thermal motion of the atoms breaks the crystal lattice structure apart; usually, a liquid is formed. When the liquid is heated enough until the atoms vaporize off the surface faster than they recondense, a gas is formed. Next,
when the gas is heated enough that the atoms collide with each other and knock their electrons off in the process, plasma is formed, the so-called ‘the fourth state of matter’.

Hence, to demonstrate the transformation towards the fourth state of matter is best described by taking water (H₂O) as an example. Ice represents the solid state of H₂O, in which the molecules of ice are fixed in lattice. The kinetic energy of each ice molecule is very weak, and therefore, the ice remains in a solid state unless extra energy is applied. If adequate energy is applied to the ice, the molecules will have more kinetic energy that allows them to agitate. The extra energy will also cause some of them to move freely. This condition turns the ice into water (liquid state). If more energy is applied to liquid, for example by boiling the water, the molecules will have more energy and get excited. As a result, the molecules are free to move and change into steam (gaseous phase). In this case, the spacing between each molecule is large enough compared to its previous states of matter. Since each molecule moves in a random manner, the kinetic energy for each molecule is different. If the steam is subjected to thermal heating, illuminated by UV or X-rays or bombardment by energetic particles, it becomes ionized.

As mention before this, plasma medium can be as conductor element instead of using metal element (1). Thus, in this research work has beneficial implications for communication systems environments. The development of antennas by using plasma medium instead of metal element is definitely a good improvement in the antenna technology. The main objective in this research is to study the analysis of plasma parameters on antenna performance at different shapes of plasma tubes. Plasma medium reacts as a radiating elements. To design and simulate the plasma antenna, Computer Simulation Technology (CST) was used.

This research is limited to using neon gas as a plasma medium. Other than that, this research used four design scheduled to be custom-made in the near future with different arrays which were a single tube, double tube, triple tube, and U-tube shapes. These tubes have fix length of 160 mm and a diameter of 10 mm. For coupling sleeve, four turns were used as the turns of coupling sleeve that give the optimum result (2). The research solely depends on the CST software simulation to acquire antenna parameters such as return loss, gain, directivity, and radiation pattern. For plasma frequency and collision frequency, the data were based on previous results which used neon gas as a plasma medium. One of the data is taken to be the reference for this research.

2. Fundamental of Plasma Parameter.
Plasma is a dispersive material that offers particular electrical properties when electromagnetic waves are applied to it. As a frequency dependent material, it also has these properties; electrical conductivity and electrical permittivity. These electrically controlled properties allow for the exploration of plasma as one of the material options in designing antennas. Hence, by understanding the relationship between plasma medium and incoming electromagnetic waves, it may lead to a promising development of plasma antennas.

In design plasma antenna, the main plasma parameters that will influence antenna performance are plasma frequency and plasma collision frequency (3). These two parameters have a very significant influence in plasma antenna behaviour if wished to be design. Equation 1 and 2 show the plasma frequency and plasma collision frequency:

\[
\omega_p = \left( \frac{n_e q_e^2}{\varepsilon_0 m_e} \right)^{\frac{1}{2}} = 8.94 \sqrt{n_e}
\]

\[
v_c = n_e \langle \sigma v \rangle / s
\]

From equation (1) and (2), the main parameters are electron densities, \(n_e\). A numerical model “Glomac” was developed by Lister et. al [6]. Glomac is a Fotran based program and a one dimensional numerical model can use to determine the electron density.
3. **Antenna Design and Structure**

The simulation for four different designs (single tube, double tube, triple tube, and U-tube) with fixed gas (neon) and pressure (10 Torr) were conducted. Four different design tubes with constant length (160 mm) and diameter (10 mm), attached with coupling sleeve (copper) were used to analyze the electrical characteristic of electromagnetic wave propagation. Computer Simulation Technology (CST) was used to design the four custom made tubes.

3.1 **Single Tube Plasma Antenna**

![Figure 1: Single tube plasma antenna](image)

Figure 1 shows the single tube of plasma antenna. The single tube plasma antenna was designed using glass borosilicate (Pyrex) with a dielectric permittivity = 4.82 and a length of 160 mm, diameter of 10 mm and thickness of 1 mm. A coupling sleeve was attached in the middle of single tube plasma antenna.

3.2 **Double Tube Plasma Antenna Array**

![Figure 2: Double tube plasma antenna array.](image)

Figure 2 illustrated the double tube plasma antenna array. With the same dimension of tubes, 160 mm and diameter of 10 mm with thickness of 1 mm, the connection between tube 1 and tube 2 is call as bridge. The bridge is design to connect tube 1 and tube 2.

3.3 **Triple Tube Plasma Antenna Array**

![Figure 3: Triple tube plasma antenna array](image)

The complete model of triple tube plasma antenna array as shown in figure 3. The dimension for all three tubes are same with height 160 mm, thickness 1mm and diameter 10mm.

3.4 **U-Shaped Tube Plasma Antenna**
Figure 4 shows the U-shaped of plasma antenna. The height and diameter are 160 mm and 10 mm.

4. Results and Analysis

4.1 Return loss, $S_{11}$

In this section, the analyses for four types of different shapes of plasma antenna is perform. Table 1 shows the analysis on data for return loss of all shapes.

| Types of Plasma Antenna                  | Resonant frequency, ($GHz$) | Return Loss, ($S_{11}$) |
|-----------------------------------------|-----------------------------|--------------------------|
| Single tube plasma antenna              | 4.150                       | -15.16                   |
| Double tube plasma antenna array        | 4.150                       | -14.86                   |
| Triple tube plasma antenna array        | 4.141                       | -14.85                   |
| U-shaped tube plasma antenna            | 4.114                       | -15.71                   |

4.2 Gain and Directivity

Table 2 shows the gain and directivity for all design plasma antenna. Based on Table 2, triple tube had the highest directivity and gain value which are 3.257 dB and 3.247 dB respectively. Second highest is double tube, followed by U-tube and single has the lowest directivity and gain.

| Types of Plasma Antenna                  | Gain, (dB)      | Directivity, (dBi) |
|-----------------------------------------|----------------|--------------------|
| Single tube plasma antenna              | 2.497           | 2.519              |
| Double tube plasma antenna array        | 3.079           | 3.088              |
| Triple tube plasma antenna array        | 3.247           | 3.257              |
| U-shaped tube plasma antenna            | 2.937           | 2.944              |

Hence, the trend could be seen where triple tube would have the highest gain and directivity followed by double tube, u-tube and lastly single tube for most of the simulation. This can be said that the shape of tubular with many array helped the antenna to give the best performance as the capability of triple tube to transmit the input power into radiation in wide magnitude and in highest radiation intensity. Overall, shape of the tube give significant effect on gain and directivity.
5. Conclusion

This research concludes that the characterization of the antenna gain, directivity and return loss, and of the plasma antenna performance using CST simulation is achieved successfully. The triple tube has the highest gain 3.247 dB with plasma frequency 1.22x10^9 rad/s and collision frequency 6.0985x10^8 collision/s caused the three array on the triple tube has the capability to transmit the input power into radiation in wide magnitude. Although high gain obtained from the triple tube, U-tube shape gave the lowest s-parameter value which is -15.71 dB. It showed that the efficiency showed by the U-tube antenna to deliver signal is better than the rest of the antenna. Hence, it can be concluded, the shape of the plasma antenna affects its performance. Moreover, the triple tube has advantages compared to other shapes because of the number of an array and the directions of the radiated signal are uniformly distributed because of charged ions were equally along the plasma column. This step involved the third objective which was to compare the performance between the four designs. It can be concluded, the objective have been achieved successfully.

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