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Effect of Plasma Antenna Shape on the Antenna Performance Using Plasma Computer Simulation Technology (CST)

A. N. Dagang[1], P. Karunamurthy[1] and H. Jaafar[2]
[1]*School of Ocean Engineering, Universiti Malaysia Terengganu, Kuala Nerus Terengganu*
[2]*Faculty of Electrical Engineering, Universiti Teknologi MARA, Dungun, Terengganu*
nazri.dagang@umt.edu.my

***Abstract*—The manipulation of fluorescent lamps in terms of size and shape was done to investigate the performance of the fluorescent-based plasma antenna. In order to fully utilize different types of commercially available fluorescent lamps, this research dealt with the effects of different shapes and types of fluorescents lamp available in the market. The aim of this research is to test the performance of fluorescent lamps with three basic shapes, namely tubular, 2U and 3U as plasma antennas by means of return loss, gain, directivity and radiation pattern. The electrical properties were determined using the current and voltage probes connected to a digital oscilloscope. Glomac programming was used to generate the average electron density and electron temperature values, using the measured electrical properties. Those parameters are crucial for calculating the plasma parameters i.e., collisions and plasma frequencies. Plasma parameter values were used in Computer Simulation Technology (CST) to simulate antenna performance. From the s-parameter or return loss results, this kind of plasma antenna radiated best at frequencies ranging from 3 to 5 GHz with the best at -41 dB using the 2U type. The gain was within the range of 0.6 dB to 2.3 dB allowing the tubular type to have the best result. The best radiation pattern was shown by tubular shaped lamp due to its uniform and symmetric main lobes in the lower and upper planes. The physical parameters of the fluorescent lamp influenced the amount of current needed to ionize the gas in the lamp. This caused the production of many electrons which altered the average electron density and its temperature. As a result, it can be concluded that by varying the shape of lamps, the plasma and collision frequencies will be affected, and consequently affecting the plasma antenna performance.**

***Index Terms*—CST; Fluorescent Lamp; Plasma Antenna.**

I. Introduction

Plasma can be used as an antenna to transmit and receive signals. The signal transmission of a plasma antenna depends on the surface wave propagation along the column. Although plasma antennas are not widely used, they are preferred than the traditional metal antenna due to many advantages. Many studies were carried out on plasma to develop the plasma antenna and make them more common as antennas. The manipulation of the type of gas as a conducting medium, radius of the discharge tube, position of the antenna (vertical and horizontal) and dimension of plasma antenna was done to investigate the performances of a plasma antenna. In recent research, the real set-up of a plasma monopole antenna agreed with the model simulated using the Computer Simulation Technology (CST) [1].

Plasma antenna technology has been developed widely since the eighties and it has numerous distinct advantages over the conventional metal antenna. In 1919, J. Hettinger suggested that the plasma (ionized gas) can be used to transmit and receive wireless signals [2]. This is a basic adaptation of the traditional antenna design that generally utilizes solid metal wires as the conducting element [3]. For a normal communication antenna, the transmitted and received signals depend on the surface wave propagation along the plasma column [4]. Previous, plasma antenna yields plasma column using the power of Radio Frequency (RF). Nowadays, alternating current (AC) biased plasma antenna exists and this kind of plasma antenna has a larger operation frequency scale and lower sustaining power [5]. The plasma is restricted in a tube for the case of a practical plasma antenna and it is electrified by the steady state current. Therefore, the outer and inner radius of the tube, the dielectric constant of the tube material and density distribution of the plasma should be taken into account in the computation to evaluate its performances [6]. It was proven that the current distribution along the antenna can be controlled by the plasma density [7] and the radial variation of the plasma affects the antenna radiation [8]. Dunn and Blum [9] stated that the response of antenna is easily affected by the changes in the profile and magnitude of electron density. The length of an antenna determines the phase velocity to be excited, chosen to be resonant with either the thermal electrons or fast primaries [10]. Due to the absence of experimental data and convenient experiments to execute, there is a need for a computer (numerical) simulation or modeling to compute the parameters and characteristics of the antennas and also to verify the parameters for future studies [11]. In a research paper by Khadir and Forooraghi [1], they experimented on a plasma monopole antenna that was made from a fluorescent tube with 0.5 m length and 0.008 m diameter. The plasma antenna’s return loss was measured using a network analyzer. The electron density of the plasma tube was calculated and those data can be used by the CST. The measurement results were compared to the result obtained by the CST. It was found that the simulation results were in good agreement with the measured results. In this research, the idea was made to be more advanced as the three different shapes of the fluorescent lamp, namely tubular, 2U and 3U were studied to discover their performances. The investigation on how the shapes could affect the performance of a plasma antenna was determined by acquiring the return loss of the signal strength, the antenna gain and directivity using the simulation of CST.

These days there is a high demand for plasma antenna compared to the traditional metal antenna. This is because the plasma antenna has a lower ringing effect compared to the metal antenna. The ringing effect causes an extra burst of electricity, which in return, wastes energy and causes the unwanted electromagnetic wave. By using plasma antenna, the extra burst of electricity can be lowered, thus, reducing energy wastage while transmitting and receiving clearer signals. At present, most of the studies on plasma antenna focus only on tubular shape. In order to fully utilize the different types of commercially available compact fluorescent lamp (CFL), this research studied the effect of different shapes of fluorescent lamps. The reason why different shapes of fluorescent lamps were tested for the performance in this research is because of the efficient designs of the fluorescent lamps. The lamp itself can be the source of light and at the same time functions as an antenna. For example, a lamp that can provide light can function as a Wi-Fi transmitter as well. In other words, the commercial CFLs in the market can serve as plasma antennas and replace the traditional metal antennas in daily use.

The aim of this research is to investigate the performance of fluorescent lamps by manipulating their shapes. The use of CST I this research was essential as it was used to design and simulate the three different shapes of fluorescent lamps, namely, tubular, 2U and 3U. The performance was inspected in terms of return loss, antenna gain, directivity and radiation pattern. The research flow was first to prepare the plasma antenna using three different shapes (tubular, 2U and 3U) of fluorescent lamps. Next, the electrical properties such as current and voltage were measured. By using Glomac programming, the plasma parameters such as electron temperature, average gas temperature and average electron density were generated. Hence, the plasma and collision frequencies can be calculated. Then, the design and simulation of plasma antenna were done by using the CST. Finally, the best shape for plasma antenna was determined and proposed after analyzing the data obtained.

II. EXPERIMENTAL SETUP

The values of current and voltage of each lamp were measured. The values were used to simulate the plasma parameters such as electron density and electron temperature using the Glomac programming. Plasma parameters such as plasma and collision frequencies can be calculated theoretically using the designated formulae. In the simulation, the fluorescent lamps were designed using the collision frequency and plasma frequency as Drude model through CST.

A. *Type of Fluorescent Lamp*

This research used the easily available type fluorescent tube, i.e., tubular, 2U and 3U shapes as shown in Figure 1 below. The tube diameters for the tubular, 2U and 3U shapes were 1.5 cm, 1.0 cm and 1.0 cm, respectively, while the tube lengths or heights were 20 cm, 10 cm, and 7.5 cm respectively.

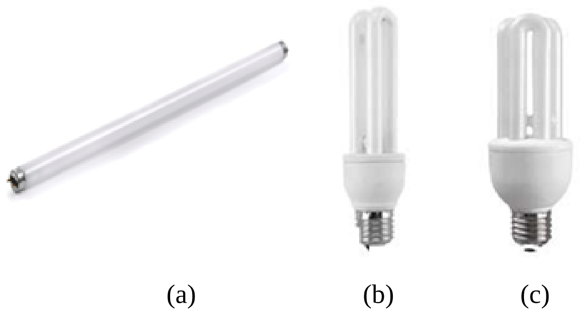

Figure 1: Fluorescent lamp used, (a) tubular, (b) 2U and (c) 3U

B. *Electrical Properties Measurement*

The electrical property measurements were important to generate plasma parameters such as electron density and temperature using the GLOMAC programming. The fluorescent lamp was ionized using the electronic ballast while the electrical properties such as current and voltage values were measured by using probes connected to a digital oscilloscope. The set-up for the current and voltage measurements of the tubular fluorescent lamp is shown in Figure 2. For 2U and 3U shaped fluorescent lamps, they were connected directly to the AC power source without an external ballast as it is built-in, while the current and voltage were measured using a digital oscilloscope. The values of the current and voltage were recorded.

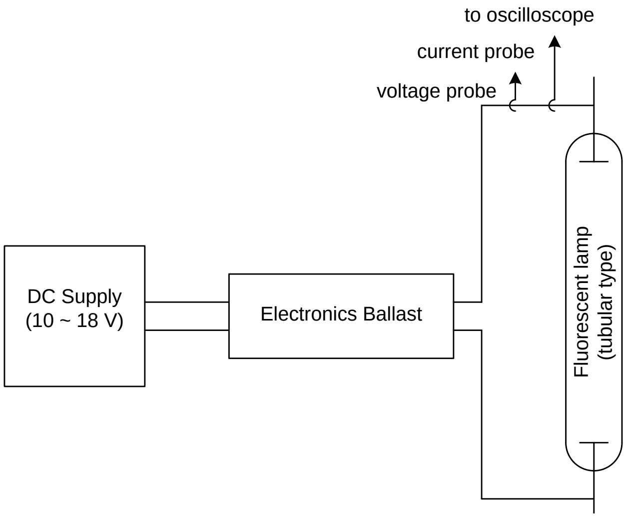

Figure 2: Black and white figure

C. *Plasma Properties Calculation*

Plasma parameters such as electron density, electron temperature, collision frequency and plasma frequency can be determined using simulation and calculation. Firstly, the electron density and temperature were determined using Glomac programming. The Glomac programming contains computer codes to generate electron temperature, average gas density and average electron density [12]. By using the outputs from the measurements of electrical properties, the values of electron temperature, and average gas and electron densities can be generated. The current and voltage values obtained from the measurements of the electrical properties with the physical properties of fluorescent lamps data such as length and radius of the fluorescent tube and other data such as the type of gas and pressure were fed into the Glomac programming. This software is beneficial to generate the plasma parameter such as electron temperature and density that are needed in order to calculate the plasma and collision frequencies. The collision and plasma frequencies were obtained in order to simulate the behavior of plasma that will be used in the CST software. Plasma frequency, ω_p, was calculated by using Equation (1) (where, ne is the density of the ionized electrons, while *e* and *m* are the electron charge and electron mass, respectively). On the other hand, collision frequency, ν_c, can be obtained using Equation (2) (where, n is the gas density, σ is the collision cross section and v_e is the electron speed.). Numerically, the plasma frequency can be calculated based on the electron number density, while the collision frequency is related to the electron temperature that can be obtained from the Glomac programming. From the calculation, the values of plasma and collision frequency were used as input parameters in the CST software for plasma antenna.

$$\omega_p = \sqrt{\frac{e^2 n_e}{\varepsilon_0 m}} \quad (1)$$

$$\nu_c = n\langle \sigma \nu_e \rangle \quad (2)$$

D. CST Simulation Setup

The CST Microwave Studio is a commercially available electromagnetic simulator based on the finite difference time domain technique. In the CST software, the behavior of the plasma is given by a Drude dispersion model which describes the transport properties of electrons in materials especially metals. The plasma frequency, ω_p and the collision frequency, vc are the so-called Drude parameters. First of all, the difference between the plasma frequency and operating frequency of the plasma antenna must be distinguished. 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 [13]. The designs for the lamps are shown in Figure 3. The signal can be transmitted or received using a coupling sleeve connected to the SMA connector. The coupling sleeve acted as an input terminal which was used to connect the fluorescent tube with the external signals and measuring equipment. In addition, the frequency was focused in the range of 1 GHz to 10 GHz for all designs in this work.

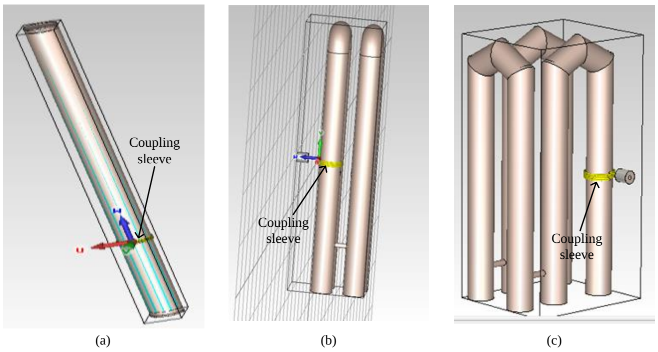

Figure 3: CST design for each type of lamp

III. RESULTS AND DISCUSSION

The main discussions circled around the effects of the shapes of plasma antenna on electrical and plasma properties, and plasma antenna performance. The effects on s-parameter or return loss and radiation pattern were also discussed.

A. Electrical Properties

The measurements of electrical properties such as current and voltage readings were important to calculate the plasma parameter calculations in this research. The results obtained from the measurements electrical properties are tabulated in Table 1. The highest value of current recorded was 887 mA for both 2U and 3U fluorescent lamps whereas for tubular the value was only 39.2 mA. The highest value of voltage recorded was 712 V for both 2U and 3U fluorescent lamps whereas for tubular the value was only 400 V. This can be considered due to the physical parameters of these lamps. The tubular lamp used in this research was a cylindrical lamp with the length of 20 cm and radius of 0.75 cm, 2U shaped lamp had two loops of U-shaped lamp, each with the length of 10 cm and radius of 0.5 cm and while the 3U shaped lamp had three loops of U-shaped lamp, each with the length of 7.5 cm and radius of 0.4 cm. Thus, the distance between the electrodes became higher, and more energy was needed in order to accelerate the particles inside the tube. Therefore, it can be said that more current and voltage are required to light up the 2U and 3U shaped lamps compared to the tubular shaped lamp.

Table 1
The Results Obtained from Electrical Properties Measurement

Parameter / Shape	Current, *I* (mA)		Voltage, *V* (V)	
	Min	Max	Min	Max
Tubular	21.3	39.2	400	400
2U	850	887	710	712
3U	850	887	710	712

B. Electron Density and Temperature Properties

The average electron density was the highest in the 2U shaped fluorescent lamp with 1.07×1019 m-3, followed by the 3U with 9.80×1017 m-3, and tubular with 1.48×1017 m-3. This was due to the higher current required to light up the lamp which caused more electrons to be ionized. Although the 2U and 3U shaped lamps had the same current and voltage values in the measurements of electrical properties, the 3U shaped lamp had a lower average electron density compared to the 2U. This can be explained as the 2U was longer and had a bigger radius than the 3U, hence, the distance from one end of the electrode to another was longer, causing the electrons to travel in a long distance. Therefore, the production of the electron was higher in 2U compared to that of in 3U. The electron temperature was the highest in 3U with 1.53 eV, followed by 2U with 1.08 eV and tubular with 0.97 eV. It can be said that the amount of current required to light up the lamp was in excessive and caused extra heat to the produced electrons. A few other factors that could highly influence the value of electron density and temperature were the volume, gas pressure, diameter, shape and electrode distance. The total volume of 2U was less compared to 3U, but the current needed was almost the same for both. Hence, it can be said that with less volume and higher current, electron density becomes higher. Furthermore, all of the fluorescent lamps used were commercially available, therefore the gas pressure inside the tube was unknown. Based on the assumption and general specifications of fluorescent lamps, the pressure can be assumed to be between 5 to 10 Torr, hence, each lamp used in the experiment might have differences in terms of pressure that could cause the differences in plasma properties as well. For a bigger diameter of the lamp, more current will be needed to ionize the gas. This causes the production of many electrons, thus, increasing the electron density. 2U had a bigger diameter than 3U, therefore, the production of the electron in 2U was larger compared to the 3U.

Table 2
The Results Obtained from Glomac Programming

Parameter / Shape	Average Electron Density, n_e (m^{-3})	Electron Temperature, T_e (eV)
Tubular	1.48×10^{17}	0.97
2U	1.07×10^{19}	1.08
3U	9.80×10^{17}	1.53

C. Plasma and Collision Frequencies

The plasma and collision frequencies are calculated and tabulated in Table 3. 2U had plasma frequency of 1.84×1011 rad/s which was the highest compared to the 3U with 5.58×1010 rad/s and tubular with 2.17×1010 rad/s. This can be considered due to the motion of electrons in fluorescent lamps. Since there were more electrons in 2U compared to any other fluorescent lamps used, the movement of electrons was also frequent compared to the others. The collision frequency was the highest in 3U with 4.58×109 collision/s followed by 2U with 2.05×109 collision/s and finally tubular with 1.53×109 collision/s. This might be due to the temperature of the electron in the 3U shaped lamp, which caused more kinetic energy among the electrons, thus, the electrons moved vigorously and collided more frequently. Therefore, it can be concluded that the collision frequency was the highest in 3U.

Table 3
The Results Obtained from Plasma Properties Calculations

Parameter / Shape	Plasma Frequency, ω_p Radian/s	Collision Frequency, ν_c Collision/s
Tubular	2.17×10^{10}	1.53×10^{9}
2U	1.84×10^{11}	2.05×10^{9}
3U	5.58×10^{10}	4.58×10^{9}

D. S-Parameters

The effects of the shape of fluorescent lamps as plasma antennas can be seen clearly in the return loss graph, gain and directivity values, and radiation pattern. Figure 4 shows the s-parameter versus frequency results for tubular, 2U, and 3U. The return loss, gain and directivity values are recorded in Table 4. Based on Figure 4, it can be seen clearly that the best return loss was -41.5327 dB produced by the 2U fluorescent lamp at 3.39 GHz, followed by tubular with the return loss of -25.9772 dB at 3.97 GHz and the worst was -19.2742 dB at 4.50 GHz produced by 3U. It was found that the 2U shaped fluorescent lamp was more effective to deliver signals compared to the 3U and tubular shaped fluorescent lamps.

From Table 4, it can be seen that 2U had the highest directivity value at 4.760 dBi, second highest was 3U with a directivity value of 4.089 dBi, and tubular had the least directivity value of 2.430 dBi. This might be the results from the high plasma frequency value of the 2U. However, a different relation can be seen in the gain values. It can be noted that the gain of 2.303 dB was produced by tubular, 2U had a gain of 1.312 dB, and 3U had the lowest gain value at 0.655 dB. This can be due to the physical properties of the tubular fluorescent lamp. The tubular shaped lamp had the longest length and biggest diameter compared to the 2U and 3U. There was only one column of conductive plasma to transmit signal, thus, the ability to transmit the input power into radiation in a specified magnitude was high in this case.

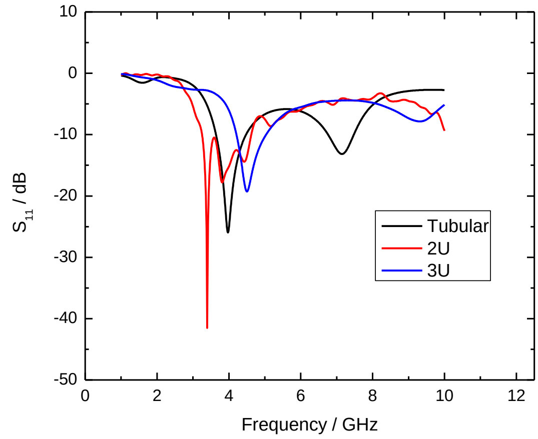

Figure 4: Graph of the S-Parameter (S11) result for the Tubular, 2U and 3U fluorescent lamps

Table 4
The S11, Gain and Directivity Result for the Tubular, 2U and 3U Fluorescent Lamps

Parameter / Shape	Frequency, f, (GHz)	Return Loss, S_{11} (dB)	Gain (dB)	Directivity (dBi)
Tubular	3.97	-25.9772	2.303	2.430
2U	3.39	-41.5327	1.312	4.760
3U	4.50	-19.2742	0.655	4.089

E. Radiation Pattern

Figures 5 to 7 show the radiation pattern for tubular, 2U and 3U in two-dimension (2D) in terms of E-plane. The plane containing the electric field vector is called E-plane and it is the direction of maximum radiation. It can be noticed that the radiation patterns were not only affected by the end of the lamp but by the whole lamp. As shown in Figure 5, the radiation pattern of the tubular lamp had the main lobe magnitude of 1.7 dB at 179.0º. The pattern simply showed that the radiation was in symmetry and uniform in upper and lower planes which means that the radiation is in omnidirectional. From Figure 6, the radiation pattern of the 2U lamp had the main lobe magnitude of 1.3 dB at 68.0º and its side level was -3.2 dB. Figure 7 shows that the radiation pattern of the 3U shaped lamp had the main lobe magnitude of -1.9 dB at 98.0º. In terms of the radiation pattern, the tubular type had the best radiation pattern compared to the 2U and 3U. The radiation of the tubular was equal in all direction in both upper and lower planes. Besides that, the tubular shaped lamp emitted signal at the widest angle and strongest strength of signal power compared to other lamps. It can be concluded that different dimensions of the lamp, in terms of length, radius and shape could affect the radiation pattern. A plasma column that is longer in length and bigger in diameter could produce a radiation pattern with a big value of the main lobe magnitude and at a wider range of angle. As for the plasma lamps with different shapes, namely the 2U and 3U, as used in this research, it can be said that the shape influences the radiation pattern. This might happens because the presence of the U shape restricts the signal radiated in a wide angle, thus, lowers the value of the main lobe magnitude.

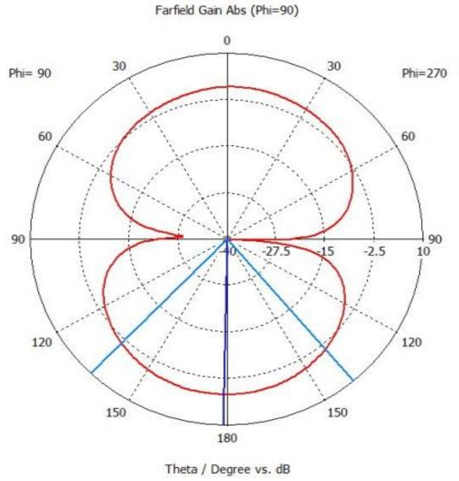

Figure 5: The radiation pattern for the Tubular type.

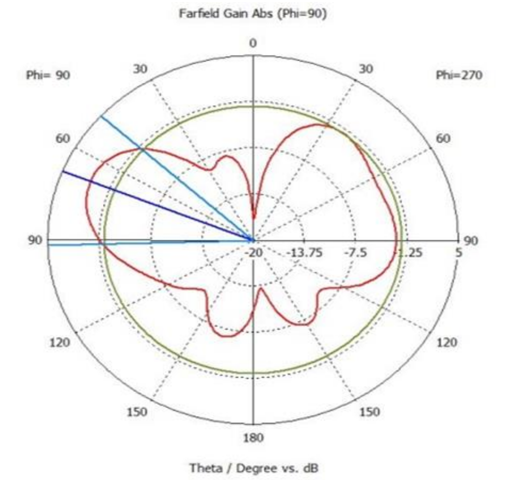

Figure 6: The radiation pattern for 2U type

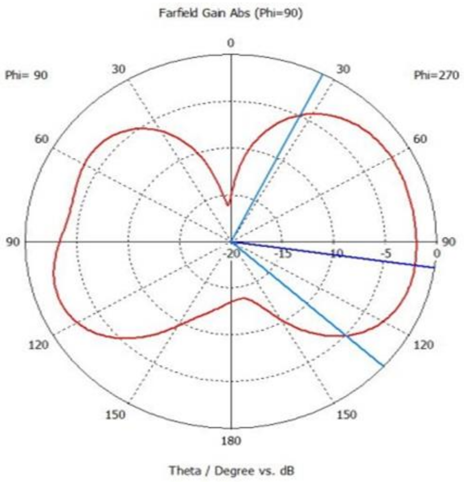

Figure 7: The radiation pattern for 3U type

IV. CONCLUSION

The characterization of the antenna gain, radiation pattern and return loss of the plasma antenna performance using the CST simulation was successfully done. It can be concluded that the shape and the physical parameters of a plasma antenna will affect its performance. The process of designing the plasma antennas using different shapes through CST was done with the aid of the Drude model in order to create the plasma material. The characterization of plasma antenna in terms of gain, radiation pattern and return loss based on CST simulation were successfully done as well. The recorded return loss value for the 2U was -41.5327 dB at 3.39 GHz and the directivity value recorded was also the highest for the 2U compared to the rest. In this case, the 2U shaped lamp can be labelled as the most effective antenna to deliver signals compared to the rest of the lamps, as it had the highest plasma frequency value. Nevertheless, a different relation can be seen in the gain values where the tubular was noted to have the highest gain value of 2.303 dB, while the radiation pattern for the tubular was symmetry in the lower and upper planes This can be the result of the physical properties of the tubular as it had the longest length, biggest diameter and greatest distribution of charged ions that were equal to the plasma column. Experimental approach with actual setup needs to be done in order to validate the antenna performance results.

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