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Research Article

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DESIGN AND DEVELOPMENT OF PLASMA ANTENNA FOR WI-FI APPLICATION

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ABSTRACT

The term plasma is often referred to as the fourth state of matter. When sufficient ionized, plasma can be a conductor element. Plasma antenna is a type of radio antenna that represents the use of ionized gas as a conducting medium instead of metal conductors. The main objective in this research is to design plasma antenna at 2.4 GHz by using commercial fluorescent tube. In this work the commercial fluorescent lamp was chosen because it was low cost to produce plasma element. The plasma antenna in this research was made from fluorescent lamp that functioned as a radiating element with target frequency at 2.4 GHz for Wi-Fi application. The commercial fluorescent lamp consisted of argon gas and mercury vapor with a diameter of 28 mm and a length 589.8 mm. The result showed that a fluorescent tube, can be used to work as a plasma antenna for Wi-Fi application.

Keywords: plasma antenna; plasma element; coupling sleeve; Wi-fi application

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1. INTRODUCTION

The industrial potential of plasma technology is well known and excellent demonstrated in several processes of microwave technology, which incorporate some use of an ionized medium. In vast majority of approaches, the plasma, or ionized volume, simply replaced a solid conductor. Highly ionized plasma is essentially a good conductor, and therefore plasma filaments can serve as transmission line elements for guiding waves, or antenna surfaces for radiation. Plasma antenna is a kind of antenna that radiate electromagnetic wave (EM) energy based on ionized gas instead of metallic conductor in antenna design. In this research work, the development using plasma medium as a conductor element instead of metal medium is investigated. New design antenna by using plasma concepts was proposed; namely monopole plasma antenna using fluorescent tube. The monopole plasma antenna using fluorescent tube is designed at frequency 2.4 GHz which is aim in wireless application. The commercially fluorescent lamp is used as a plasma antenna. Coupling technique was used in this design.

1.1. Fundamental of Plasma

First and foremost, plasma is an ionized gas. Hence, it consists of positive (and negative) ions and electrons, as well as neutral species. The term plasma is used to describe a wide variety of macroscopically neutral substances containing many interacting free electrons and ionized atoms or molecules, which exhibit collective behavior due to the long-range Coulomb forces. In fact, the word 'plasma' derived from the Greek and it means "something molded". It was applied for the first time by Tonks and Langmuir in 1929, to describe the inner region, remote from the boundaries of a glowing ionized gas produced by electrical discharge in a tube [1].

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'.

Plasma is not usually made simply by heating up a container of gas. Typically, in the laboratory, a small amount of gas is heated and ionized by driving an electric current through it or by shining radio waves into it. Generally, these means of plasma formation give energy to free electrons in the plasma directly and then electron-atom collisions liberate more electrons and the process cascades until the desired degree of ionization is achieved.

1.2 Parameters of Plasma Physics for Plasma Antenna

Plasma medium can be a good conductor when it is highly ionized and from this concept, the plasma medium can replace the metallic medium. Plasma filaments can serve as transmission line elements for guiding waves, or antenna surfaces for radiation. Therefore, it is necessary to understand the interaction between plasma medium and electromagnetic waves. The following section explains plasma parameter; plasma frequency and collision frequency. This parameters need to be considered when to design plasma antenna.

1.2.1 Plasma Frequency

One must distinguish between plasma frequency and the operating frequency of the plasma antenna. The plasma frequency is a measure of the amount of ionization in the plasma and the operating frequency of the plasma antenna is the same as the operating frequency of a metal antenna. The plasma frequency of a metal antenna is fixed in the X-ray region of the electromagnetic spectrum whereas the plasma frequency of the plasma antenna can be varied. The equation for plasma frequency is shows in equation (1):

$$\omega_p = \left(\frac{n_e q_e^2}{\varepsilon_0 m_e}\right)^{\frac{1}{2}} \tag{1}$$

Where:

n_e = Electron density

q_e = 1.60217653 x 10^{-19} C is the electron charge,

m_e = 9.1093826 x 10^{-31}kg is the electron mass.

ε_0 = 8.8541878 x 10^{-12} $\frac{F}{m}$ Free space permittivity

1.2.2 Collision Frequency

In studying plasma behavior, one of the plasma parameters that need to be identified is plasma collision frequency. Knowledge of the dependence of the effective electron-neutral collision in noble gas, such as argon, is very important in order to understand many of the plasma processes, especially for its fundamental and applications. This type of collision frequency is often referred to evaluate the energy transfer between particles. The collision frequency that occurs in gases is important in radio frequency field. The number of collision per unit time or collision frequency, v_c is,

$$v_c = n_e \langle \sigma v \rangle \quad 1/s \tag{2}$$

Where :

v_c = Collision frequency

n_e = Electron density

σ = Collision cross section

v = electron speed

2. ANTENNA STRUCTURE AND DESIGN

As initial requirements for monopole plasma antenna using fluorescent tube, the design was based on an operating frequency of 2.4 GHz. The dielectric tubes used in the simulation were made from lossy glass borosilicate (Pyrex) with permittivity at 4.82 and the thickness of the glass was 1 mm. The plasma was defined by using the Drude model (CST software). The schematic diagram of a monopole plasma antenna is shown in Fig.1.

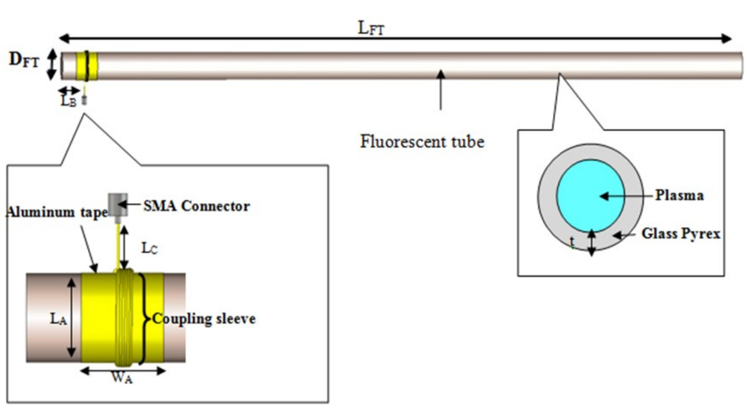


Fig.1. The structure of a monopole plasma antenna.

Fig. 1 shows the structure of a monopole plasma antenna using commercially available fluorescent tube which is the glass is from borosilicate (Pyrex) with permittivity at 4.82 with

589.8 mm in length ($\boldsymbol{L}_{\mathbf{FT}}$) and diameter 28 mm ($\boldsymbol{D}_{\mathbf{FT}}$). The gas filled inside the fluorescent tube was argon gas and a drop of mercury vapor. The gas argon was added to the fluorescent tube to assist in starting since the vapor pressure of mercury is very low initially.

Before the radiation began, the signals were connected to the tube with a coupler. This is called coupling sleeve. When the RF signals were applied to the coupling sleeve, the RF current flowed in the coil and generated an RF electric field. In addition, at the same time when the voltage was applied to the monopole plasma antenna, an electric field was produced and this electric field caused the current to flow in the plasma medium. The combination of current oscillated on the surface of the metal and this was caused by the disturbing currents in the interface between plasma and coupling sleeve. On top of that, these two electric fields were emitted from the monopole plasma antenna and propagated through the space [2]. Nonetheless, in this work, the coupling sleeve with a width W_{A} of 18 mm was mounted 12 mm below at the lower end of the fluorescent tube. The coupling sleeve consisted of aluminum tape and copper wire. The copper wire was wrapped tightly at the aluminum tape. The function of coupling sleeve was to couple the RF and the plasma element inside the fluorescent tube. The RF current from the network analyzer flowed in the coupling sleeve and generated an RF electric field to be coupled with the plasma column inside the discharge tube. Besides, the SMA connector was applied to maintain the 50 Ohms impedance for the RF generator. The power to energize the fluorescent tube was supplied by a set of electronic ballast with specification of 220-240V, 50-60Hz. The electronic ballast was chosen compared to magnetic ballast because electronic ballast is lighter in weight than magnetic ballast and it is more efficient compared to magnetic ballast [3].

Moreover, the length of plasma, diameter of plasma, number of turn of copper coil, diameter of copper wire, distance between coupling sleeve and SMA connector, and position coupling sleeve at the fluorescent tubes were optimized to obtain the best results. Besides, the effect of width of aluminum tape was also investigated for antenna performance. The parameters and dimension of the monopole plasma antenna are tabulated in Table 1. The comparative results of the proposed antenna performance are described and further discussed in terms of reflection coefficient, gain, VSWR, and radiation patterns.

Table 1. Parameters and dimension of monopole plasma antenna

Parameter	Label	Dimension(mm)
Length of monopole plasma antenna	L_{FT}	589.8
Diameter of monopole plasma antenna	D_{FT}	28
Thickness glass	t	1
Length of aluminum tape	L_A	30
Position Coupling Sleeve at the monopole plasma antenna	L_B	22
Distance from SMA connector to coupling sleeve	L_C	9
Width of aluminum tape	W_A	18
Diameter copper coil	D_C	0.25

2.1 Coupling Sleeve Structure

In contrast to conventional metallic antennas, it is impossible to make a direct electrical contact with the plasma conductor because the plasma is encapsulated in a dielectric tube. For that reason, it was necessary to use capacitive coupling to launch surface waves as a way to radiate radio signals. Only a small portion of monopole plasma antenna was covered with coupling sleeve. The structure of coupling sleeve as shown in Fig. 2.

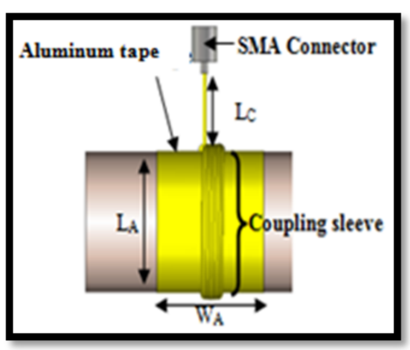


Fig. 2. Coupling sleeve structure.

3. RESULT AND DISCUSSIONS

3.1 Effects of the Length of Monopole Plasma Antenna.

Fig. 3 shows the reflection coefficient, S_{11} results for simulated when optimized length plasma column from 504.8 mm ≤ L_{FT}≤ 629.8 mm with increment 40.0 mm. From simulation results clearly shows that when increase the length of plasma antenna the resonant frequency will shifted to the high frequency. However, when increase the length of plasma antenna, the plasma frequency also changes. Thus it will affect the resonant frequency of the antenna. This behavior indicates that the resonant frequency of plasma antenna can be achieved by controlling the plasma frequency. Hence, this analysis proved that, the length of monopole plasma antenna has a greater influence on the operating frequency.

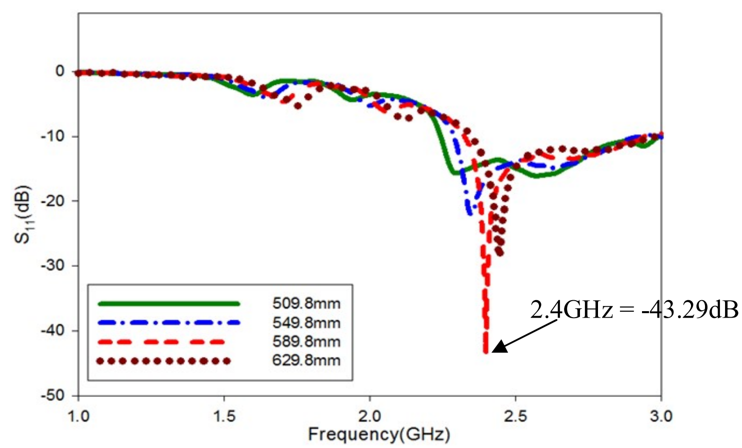


Fig.3. The effects on reflection coefficient, S_{11} due to change of length monopole plasma antenna**.**

3.2 Effects of Diameter Plasma Antenna

The effect of the diameter on fluorescent tube has been analyzed to observe which value gives the better result. The diameter of plasma antenna are varies from 20 mm until 36 mm with an increment of 4 mm. From Fig. 4 shows that, the reflection coefficients, S_{11} fluctuated when the diameter of the plasma column was varied. It was because; when the diameter of plasma antenna was changed, the electron density of plasma changed as well. Thus, it influenced the performance of the antenna. From the observation, the best result providing good impedance at 2.4 GHz was obtained when the diameter was 28 mm with s-parameter was equal to -43.29 dB. Hence, 28mm was chosen for the final design.

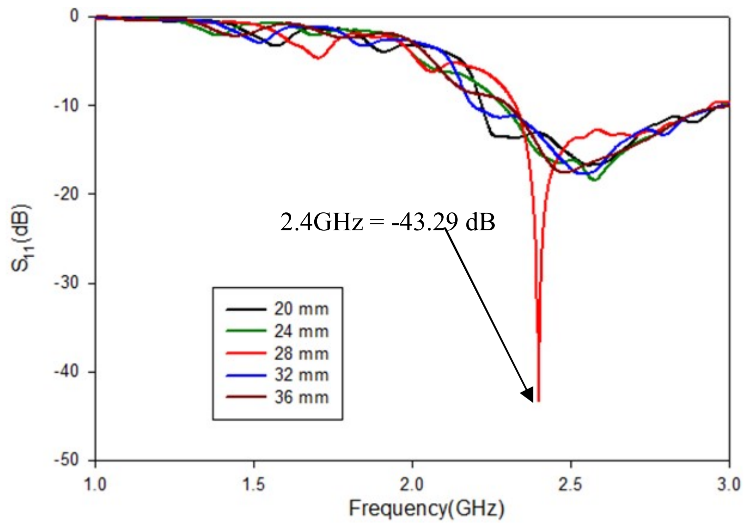


Fig.4. The effects on reflection coefficient, S_{11} due to change of the diameter of plasma antenna.

3.3 Simulation and Measurement Result

Fig. 5 exhibits the comparison between simulation and measurement results of reflection coefficient, S_{11} for the monopole plasma antenna using fluorescent tube. The measured results indicated that the antenna was capable in operating at 2.4 GHz. The simulated result during plasma ON is -43.29 dB at frequency 2.4 GHz while for measured result the reflection coefficient, S_{11} at 2.4 GHz is -22.10 dB. Result measurement for reflection coefficient, S_{11} during plasma OFF at frequency 2.4 GHz is -8.42 dB. This is shown that, during plasma OFF there is no conductor element and as a result cannot performance as an antenna.

From Fig. 5, the measured result seems to have lower value of S_{11} than simulated result at frequency 2.4 GHz is presumably due to the parasitic effect from imperfect solder between SMA connector and coupling sleeve. Besides, the difference between simulation and measurement might be due to the current flow to fluorescent tube that might not be consistent and affected the condition of plasma produced in the real experiment. However, in general, a good agreement has been achieved between simulation and measurement.

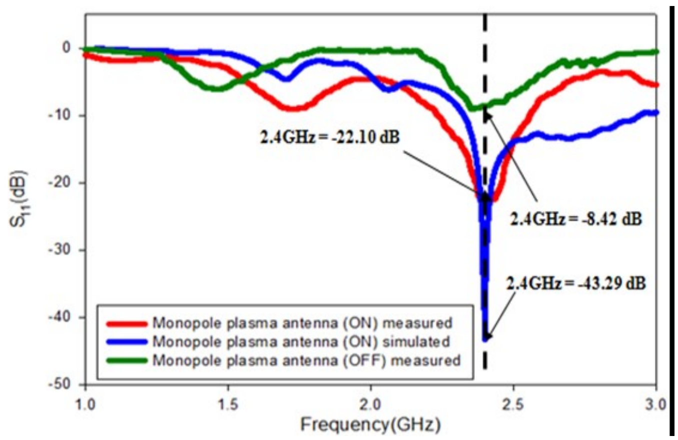
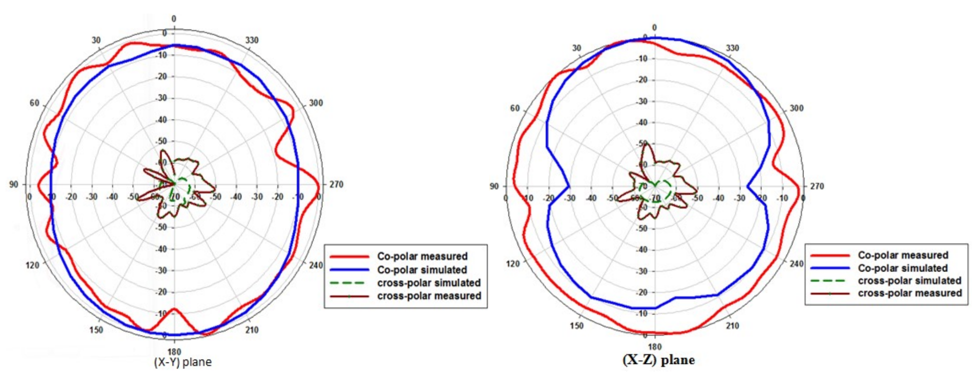


Fig.5. Simulated and measured reflection coefficient, S_{11} for monopole plasma antenna.

Apart from that, the radiation patterns of monopole plasma antennas during ON were observed in both simulated and measured scenarios. The measured and simulated radiation patterns at E-plane (phi=90°) for the monopole plasma antenna excited at 2.4 GHz are shown in Fig. 6. The results show that the radiation patterns of cylindrical monopole plasma antenna in H-plane direction (at phi=0^o) does not give significant effect in radiation pattern, thus the radiation patterns is obvious and can be observed in E-plane direction (at phi=90º).

Good agreement and well behaved radiation patterns were obtained. This was attributed to the omni-directional characteristics of monopole plasma antenna. In comparison, the measured scenarios displayed some distortions in terms of radiation pattern which were due to losses and connectivity impurities. Besides, the cross-polar radiation pattern is lower than -10 dBi.



(a) (b)

Fig.6. Simulated and measured radiation patterns of monopole plasma antenna (ON) at 2.4 GHz in (a) H-Plane and (b) E-Plane.

4. CONCLUSION

In conclusion, the simulation and the measurement results of plasma antenna showed that a simple fluorescent tube, used for household applications, can be used to work as a plasma antenna for Wi-Fi application. This could be done by implementing the coupling technique by applying AC voltage 240 V across the electrodes of fluorescent tube. In this research work, the plasma antenna was fabricated by using commercial fluorescent tube with a length of 589.8 mm and a diameter of 28 mm, as well as being measured at frequency 2.4 GHz.

Besides, the plasma antenna prototype yielded reflection coefficient, S_{11} < -10 dB, which was suitable for indoor wireless transmission applications. In addition, the results from measurements of each structure seemed to agree well with the simulation results.

Therefore, the commercial fluorescent lamp has the potential to be used as a good conductor element and it is also a low-cost plasma antenna.

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