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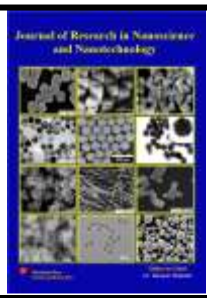

Electron-Neutral Collision Frequency Determination of Plasma Medium

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ABSTRACT

Plasma medium is often referred to as the fourth state of matter, since it has properties very much different from those of the gaseous, liquid, and solid states. The simple and available plasma medium in the market is fluorescent lamp. In standard fluorescent lamps, mercury vapor pressure plays one of the key roles to define electron density. In view of the fact that, electrical conductivity of plasma depends on electron density and electron-neutral collision, the vapor pressure plays important role in determining plasma electrical conductivity too, which is important properties in determining the performance of plasma medium if they are used to radiate microwave signals. Therefore, as reported in this paper, the electron-neutral collision is estimated by conducting experiments and simulations. It was concluded from the results that the electron-neutral collision of commercially available plasma medium is 900 MHz.

Keywords:
Plasma electron-neutral collision frequency;
plasma medium; cold-plasma

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1. Introduction

Plasma is a dispersive material which offers electrical properties when electromagnetic waves are applied to it. As a frequency dependent material, it also has these properties; electrical conductivity, electrical permittivity, and magnetic permeability. These electrically controlled properties allow the exploration of plasma as one of material options in designing antennas. By understanding the relation between plasma medium and incoming electromagnetic waves, it may lead to a promising development of plasma antennas [1-17]. Plasma medium is formed by ions and electrons; therefore, it is necessary to understand the interaction between plasma medium and electromagnetic waves. One should understand the plasma parameters [2,18,19] such as plasma conductivity [20,22], plasma critical frequency [21] and plasma permittivity [23,26]. The plasma discussed in this paper is an assumption of homogenous plasma.

There are two types of plasma which are collision-less and collisional plasmas. In this research work, the plasma is modeled as a cold-plasma based on the Drude model. The effect of electron collision is associated with the model. The model is developed to represent the commercially available plasma source used in experimental activities. The plasma source is assumed to have low pressure argon and mercury vapor encapsulated in pyrex glass tube. The model is developed in CST software with the assumption that the isotropic plasma has uniform intensity in all directions. Regarding the Drude model, the epsilon infinity is equal to 1 thus simplifying the permittivity equation as derived in Equation 1, with an introduction of v_{col} (collision effect).

$$\varepsilon_r = (1 - \frac{n_e q^2}{\omega \varepsilon_o m_e (\omega - j v_{col})}) = (1 - \frac{{\omega_p}^2}{\omega(\omega - j v_{col})}) \tag{1}$$

Knowledge of the dependence of the effective electron-neutral collision in noble gas such as argon is very important to understand many plasma processes especially for their fundamental and applications. This type of collision frequency is often referred to as evaluate the energy transfer between particles. The collision frequency that occurs in gases is important in radio frequency field as highlighted in [23]. Collisional plasmas can be divided into two cases, which are partially ionized plasmas and fully ionized plasmas [1]. When discussing partially ionized plasmas, the dominant collisional process is between electrons and neutrals. In general, as the partially ionized plasma is associated with low pressure plasma, collisions with neutral particles dominate all other elastic processes in low pressure discharge [23,24].

In 1981, the effective collision frequency of electrons in noble gases was studied in [25]. The Maxwellian distribution of electron particles was assumed to conduct the study. The group has compared their results with other previous published studies within the year of 1960 and 1978. The estimation was conducted for the noble gases such as helium, neon, argon, krypton and xenon. The following are the equations to estimate effective collision frequency between electrons and argon atoms [24].

$$v_{col} = N_{AR}\left(2.58 \times 10^{-12} {T_e}^{-0.96} + 2.25 \times 10^{-23} {T_e}^{2.29}\right) \qquad for\ (6 \times 10^2 K \ll T_e \ll 1.4 \times 10^4 K) \tag{2}$$

or

$$v_{col} = N_{AR}\left(3.7 \times 10^{-8} {T_e}^{-0.315}\right) \qquad for\ (2.5 \times 10^2 K \ll T_e \ll 6 \times 10^2 K) \tag{3}$$

where the T_e is electron temperature and N_{AR} is argon gas density. For example, if the T_e of fluorescent lamp is known to be 11000K, and the argon gas density is 10^{23} m^{-3} at particular pressure, thus the estimated v_{col} will be 4000 x 10^6 Hz. This paper aims to determine the electron-neutral collision frequency of commercially available plasma source so that it can be modelled in computer advanced software such as CST for antenna designs.

2. Determination of Electron-Neutral Collision Frequency

To calculate the approximated value of electron-neutral collision frequency, an experimental approach is needed. Complex permittivity that defines plasma characteristics varies with electron-neutral collision frequency. As an example, three values of electron-neutral collision frequency which have different complex permittivity graph curves are shown in Figure 1.

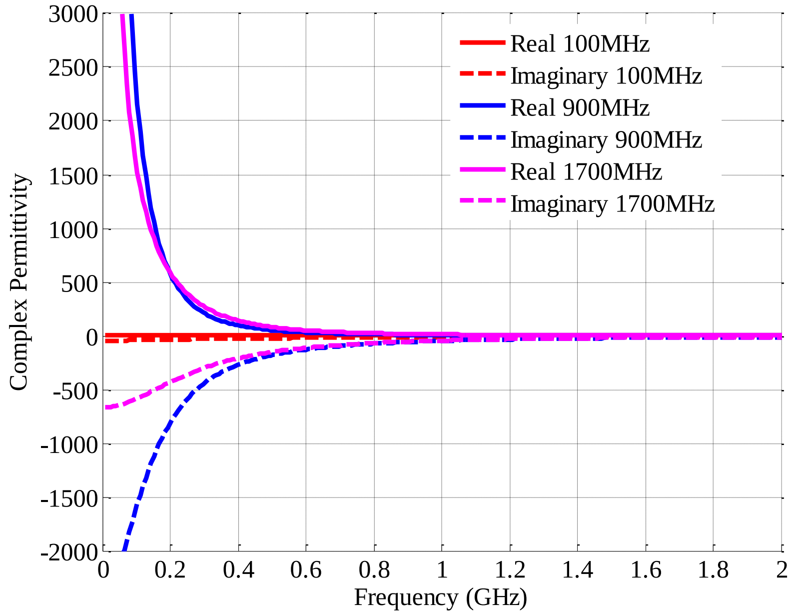

Fig. 1. Curve patterns of plasma complex permittivity for three different values of electron-neutral collision frequency (100 MHz, 900 MHz, and 1700 MHz respectively)

The real permittivity is related to the energy stored in the medium while the imaginary permittivity is related to the dissipation or loss in the medium. Therefore, it is quite complex to define a model of plasma as its parameters vary with time and frequency. Yet, an experimental approach can be taken to start a process of estimating these parameters. For that reason, in this study, we aim to compare the measured and the simulated radiation patterns of the antenna illustrated in Figure 2. By doing so, an estimation value of electron-neutral collision frequency can be made. In order to have a quick analysis, based on Figure 1. There are two conditions to better understand the electromagnetic wave propagation in plasma.

i) when the electromagnetic wave frequency is lower than plasma frequency ($\omega < \omega_p$), the relative permittivity is negative value. Thus, the propagation constant turns into imaginary. Therefore, the electromagnetic wave will be reflected as the plasma behaves as conductor with low conductivity. If considering collisional plasma, the electromagnetic wave could also be absorbed however it depends on electron-neutral collision frequency.
ii) when the plasma frequency is lower than electromagnetic wave frequency ($\omega > \omega_p$), the relative permittivity of plasma becomes positive, and the propagation constant is real. Consequently, plasma has dielectric properties that is electronically controlled. In this case, the electromagnetic waves will penetrate the plasma medium and suffer from losses.

3. Measurement Setup

A CFL with a physical height equal to 40 mm from ground plane is expected to reflect electromagnetic wave radiated by a monopole antenna as illustrated in Figure 2. The distance between CFL's surface and central monopole antenna resonating at 4 GHz is 0.25λ.

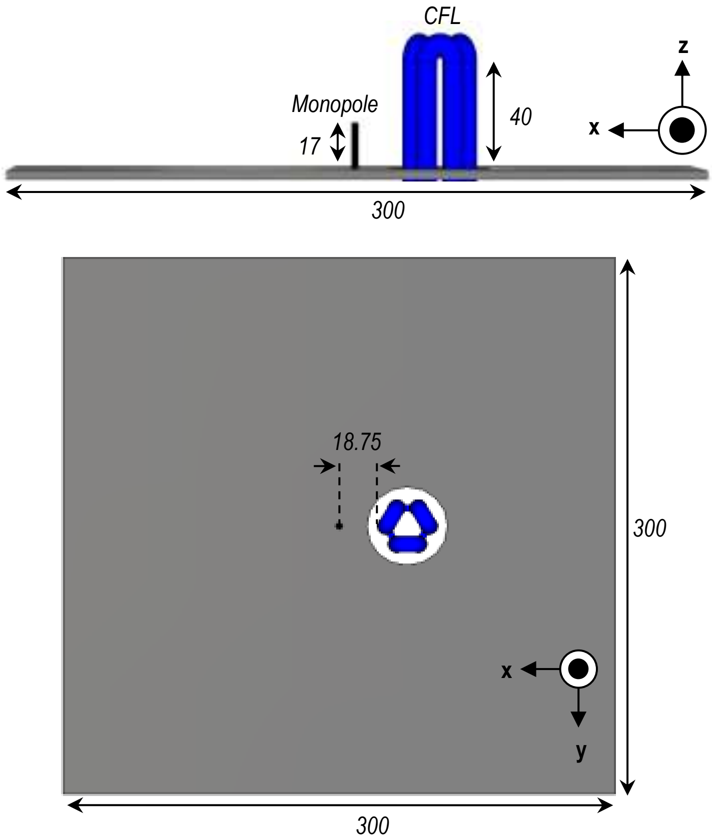

Fig. 2. Schematic diagram of antenna used for the radiation pattern measurement (Unit in mm)

The monopole height is 17 mm and the ground plane dimension is 4λ x 4λ with a thickness of 3 mm. The frequency is swept from 1.5 GHz to 5.5 GHz to observe the evolution of radiation pattern regardless the reflection coefficient other than at resonating frequency. The measurements were conducted in Stargate 32 SATIMO anechoic chamber.

4. Result Analysis

The radiation patterns are compared between measurement and simulation. The simulated model is defined with plasma angular frequency equals 43.9823 x 10^9 rad/s and electron-neutral-collision frequency is equivalent to 900 MHz. The first assumption of the collision frequency is made with regard to the work of Borg *et al.*, [26,27]. The results for frequency 1.5 GHz, 2 GHz, 2.5 GHz and 3 GHz are shown in Figure 3, while the results for frequency from 3.5 GHz until 5.5 GHz are shown in Figure 4. In Figure 3, the simulated and measured radiation patterns only start to have similar patterns at broadside direction from 2 GHz.

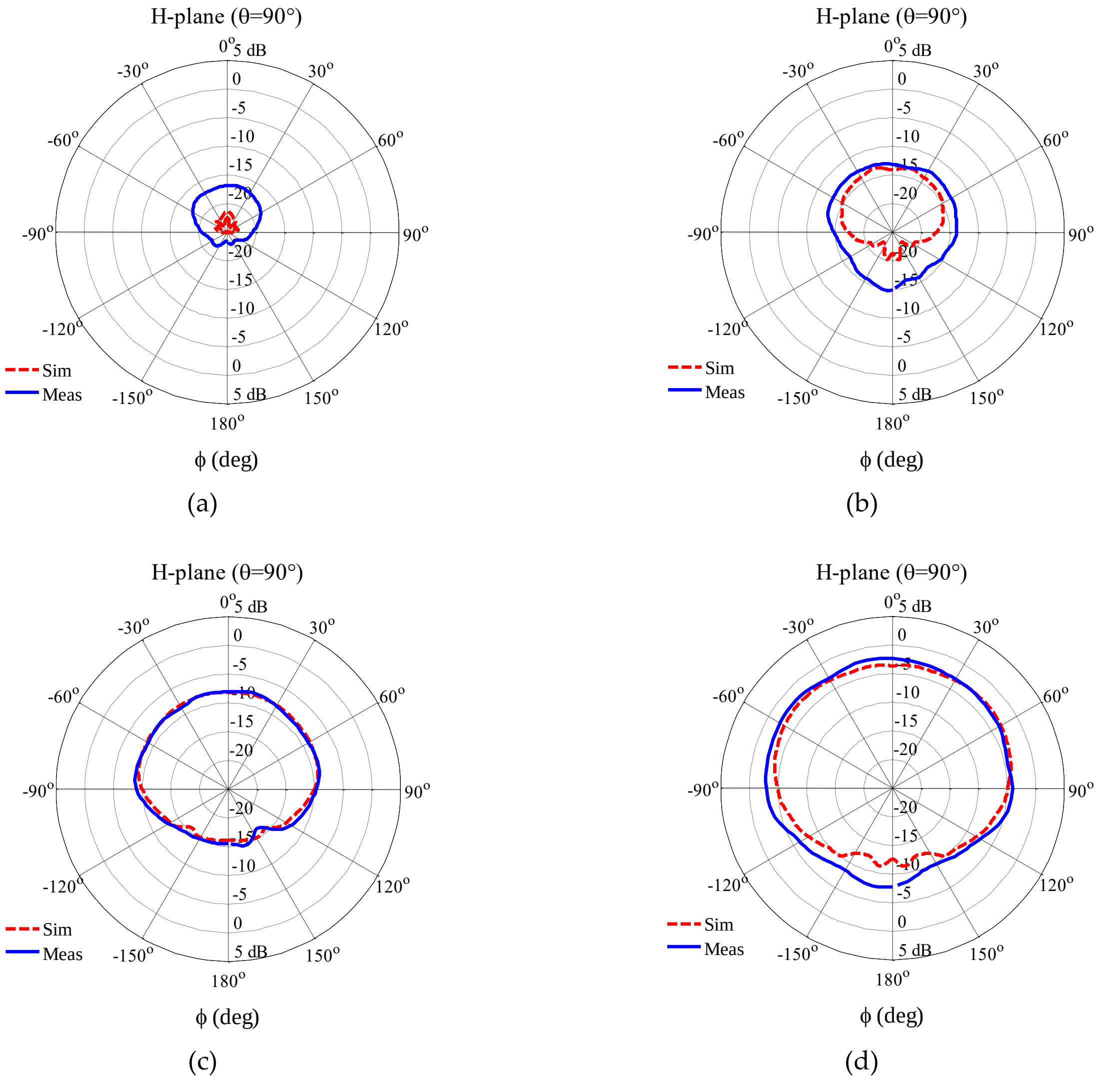

Fig. 3. Measured and simulated radiation patterns, E_θ components. (a) 1.5 GHz (b) 2 GHz (c) 2.5 GHz (d) 3 GHz

In Figure 4, the results remain comparable between simulation and measurement and continue to have similar cardioids shapes until 5.5 GHz. The pattern evolution somehow validates that the plasma which has been modeled in simulation is corresponding to actual plasma source. This is satisfactory to characterize the CFLs in simulation for the frequency starting from 2.0 GHz until 5.5 GHz. The measured and simulated gains are depicted in Figure 5. The figure emphasizes that the defined plasma model gives a similar gain curve if compared to the measured one.

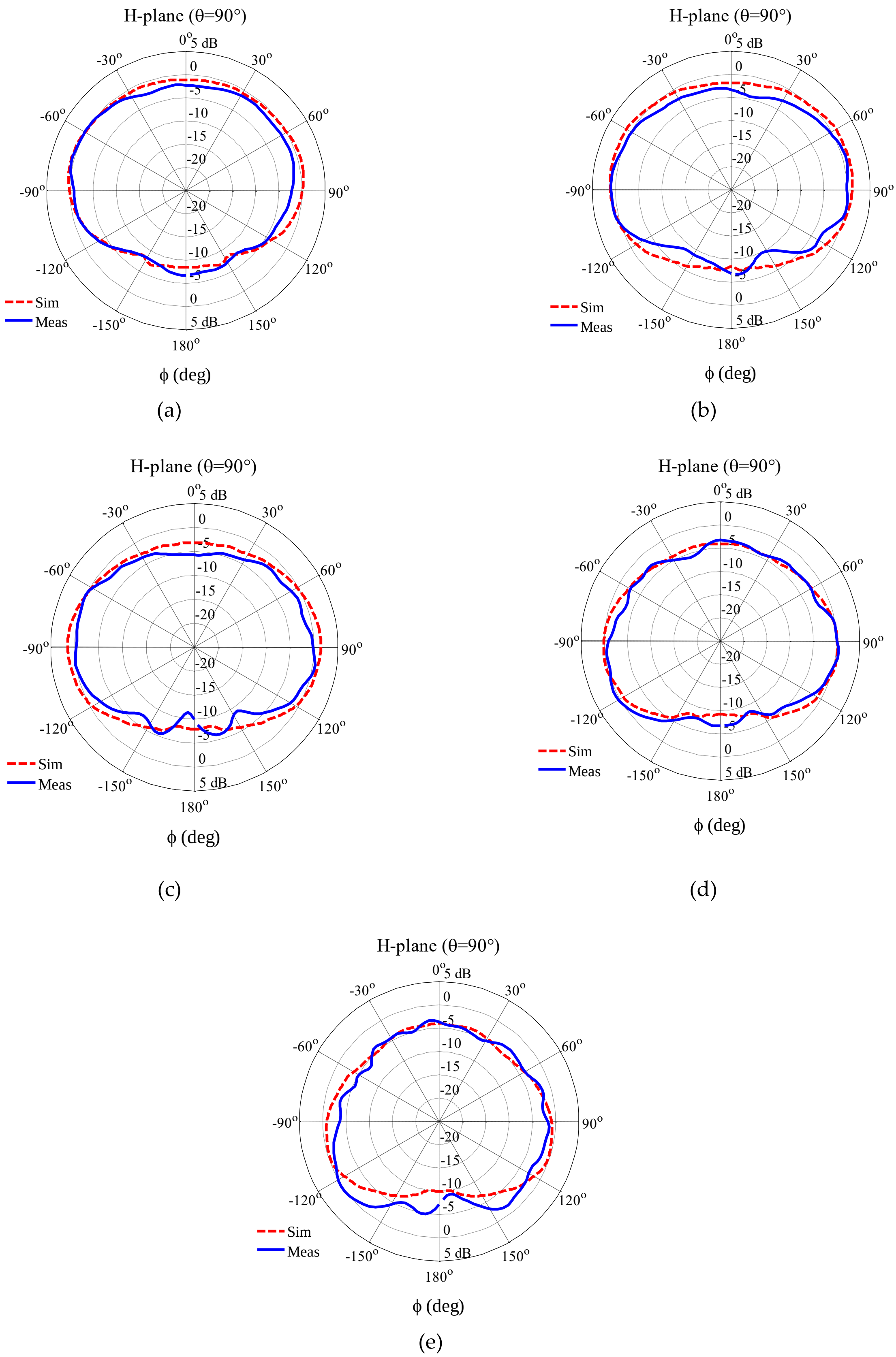

Fig. 4. Measured and simulated radiation patterns, E_θ components. (a) 3.5 GHz (b) 4 GHz (c) 4.5 GHz (d) 5 GHz (e) 5.5 GHz

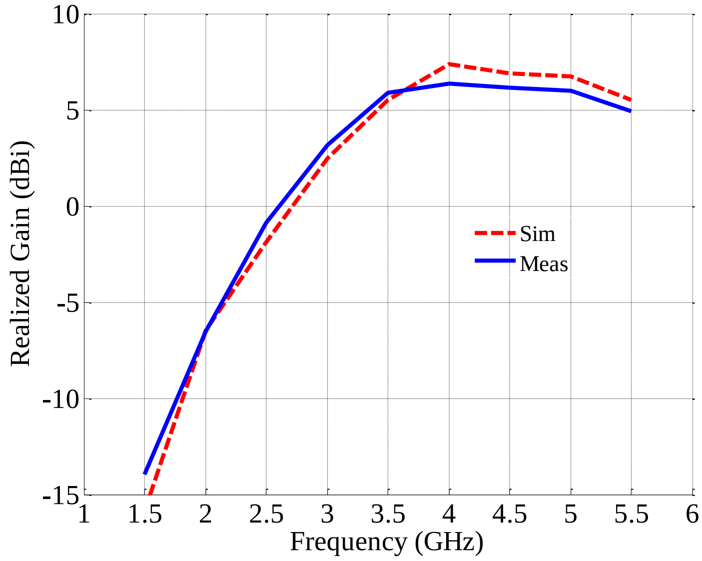

Fig. 5. The antenna gains in the maximum beam direction

Again, as to reassure the correct electron-neutral collision frequency has been selected. A set of simulations was conducted by varying the value of electron-neutral collision frequency from 100 MHz until 3000 MHz. The results are depicted in Figure 6.

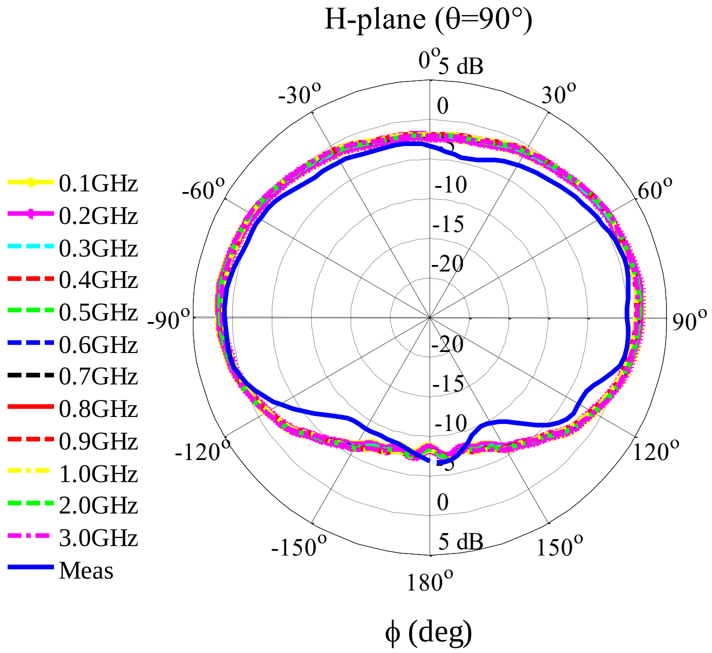

Fig. 6. Effect of electron-neutral collision frequency on radiation pattern, E_θ components at 4 GHz

As illustrated in Figure 6, the effect of electron-neutral collision frequency on radiation pattern is negligible as the frequency increases from 100 MHz to 3000 MHz. Therefore, the plasma model used in the simulations is adequate enough to represent actual plasma source in forecasting radiation pattern of plasma reflector antenna.

5. Summary of Plasma Parameters Estimation

Based on the isolation experiments, the plasma frequency is estimated to occur at 7 GHz and to 8 GHz where the transmission of electromagnetic wave in plasma medium is cutoff. In order to come out with one fix value of plasma frequency, the 7 GHz frequency is chosen. The measured and simulation results showed similar radiation patterns at the broadside direction starting at 2 GHz until 5.5 GHz when plasma source is placed near to central monopole antenna resonate at 4 GHz. Therefore, the experimental results have proven that the plasma model used in the simulation is corresponding to actual plasma source when it works as reflector elements. The variation of electron-collision frequency from 100 MHz up to 3000 MHz has no significant effect on reflector radiation patterns. Therefore, the initial value of electron-collision frequency (900 MHz) can be used to model the plasma.

6. Conclusions

This A brief review of plasma as the fourth state of matters has been discussed in the beginning of this chapter. Series of plasma equations have been derived starting with the single particle motion. Elaboration of plasma equations for the two classifications of plasma which are collision and collision less plasma was also explained. The cutoff frequency of plasma is very crucial to define plasma working region. As the plasma complex permittivity is also depending on the cutoff and transmitting radio frequencies, it is necessary to estimate the values of these two parameters. An experimental approach has been taken to get an approximation of plasma cutoff frequency and finally the frequency of 7 GHz is chosen to be plasma frequency for this entire work. As the experiments were conducted with plasma worked as reflector, the model used in simulation can be used to represent the actual plasma source for any reflector configurations. The electron-neutral collision frequency is estimated to be 900 MHz and reassurance steps have been taken by varying its value from 100 MHz to 3000 MHz and the effect of reflector radiation patterns was observed. In conclusion, there is no significant effect occurred and hence the initial value is adequate to represent the actual plasma model. The performance of the defined plasma model for reflector antenna configurations will be explained in the following chapter. The similarity between measured and simulated results will again confirm the defined plasma model.

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