Design, Simulation and Implementation of a Pre-ionized Coupled Plasma Antenna at VHF Band

Payam Darvish *, Amin B. Gorji *, and Bijan Zakeri *
*Faculty of Electrical and Computer Engineering, Babol Noshirvani University of Technology, Babol, Iran
payam_219@yahoo.com, amin.gorji@stu.nit.ac.ir, zakeri@nit.ac.ir

Abstract: ***Plasma Antenna is a new and efficient technology that has been introduced in recent years. In this area, previous works has generally focused more on experimental results. In this paper, a basic theory of the plasma material is introduced. Then a design of a Plasma antenna based on these theories is presented at VHF band. The simulation is performed by using the practical software CST Microwave Studio Suite 2011. In order to validate the simulation results of the designed Plasma antenna, an implementation of proposed antenna is performed. Results of experimental measurement of implemented antenna show a good agreement with the simulation results which has been obtained based on proposed design procedure of Plasma antenna.***

Keywords: Capacitive coupler, fluorescent tube, plasma antenna; plasma frequency, pre ionizing, VHF band

I. Introduction

In 1919, J.Hettinger suggested that ionized gas (plasma) can be used to transmit and receive signal and among the years of 1960 to 1970, Askaryan and Raveskii proved this suggestion using experimental procedures [1]. In the following sections first the plasma material is introduced and then the features of plasma antenna are investigated.

A. Plasma

On earth we live upon an island of ordinary matter. The different states of matter generally found on earth are solid, liquid, and gas. Sir William Crookes, an English physicist identified a fourth state of matter, in 1879 [1]. Later in 1923 it was named as plasma by an American physicist Longmuir [2]. For him it resembled to be as blood plasma. He says, “in tube experiment of Crookes, except near the electrodes, where there are sheaths containing very few electrons, the ionized gas contains ions and electrons in about equal numbers so that the resultant space charge is very small”. We shall use the name plasma to describe this region containing balanced charges of ions and electrons. Plasmas carry electrical currents and generate magnetic fields [3].

B. Plasma Antenna

Plasma antenna technology employs ionized gas enclosed in a tube (or other enclosure) as the conducting element of an antenna [1,4]. This is a fundamental change from traditional antenna design that generally employs solid metal wires as the conducting element. Ionized gas (plasma) is an efficient conducting element with a number of important advantages [3]. The design allows for extremely short pulses, important to many forms of digital communication and radars [1].

One fundamental distinguishing feature of a plasma antenna is that the gas ionizing process can manipulate resistance [3]. A second fundamental distinguishing feature is that after sending a pulse the plasma antenna can be deionized, eliminating the ringing associated with traditional metal elements [3]. Ringing and the associated noise of a metal antenna can severely limit capabilities in high frequency short pulse transmissions.

When voltage applied to an antenna, electric field is produced and this electric field causes current to flow in the antenna [3]. Due to current flow, magnetic field is then produced. These two fields are emitted from an antenna and propagate through space over very long distances. The applications of plasma antenna is in high speed digital communication and radar system, radio antenna, stealth for military application and can be used for transmission and modulation techniques (PM, AM, FM) [2]. The advantages of plasma antenna are in its high power, enhanced bandwidth, higher efficiency, lower thermal noise, perfect reflector, low in weight, smaller in size, and improved reliability [3].

Most of the works on plasma antennas include little theory and due to this fact, most of them have not engaged with any kind of simulations. Plasma is a dispersive environment and it has its own parameters. First we should know the basic parameters then use them for our application or defining the plasma material for simulation of plasma antenna.

This paper deals with simulating the plasma antenna in the practical program CST Microwave Studio Suite 2011 and implementation and test of the antenna in VHF band. Section II explains the structure of a basic plasma antenna and introduces the basic parameters of plasma environment. At last, section III explains the simulation design, implementation of our plasma antenna and comparison of results obtained by simulation and experiment.

II. Structure of Plasma Antenna

A. Ionization

For research purposes, fluorescent and neon tubes are used to build plasma antenna since they are inexpensive. First the gas in tubes should be ionized to transmit and receive signal. With applying enough voltage at the two sides of electrodes the gas can be ionized.

B. Basic Theory and Plasma Parameters

Plasma in terms of electromagnetic properties is a non-homogeneous, non-linear and dispersive environment. Permeability (μ), conductivity (σ) and permittivity (ε) in plasma can be varied in terms of frequency and other parameters and make plasma a special environment. As a result, for any frequency of the incident wave and in any density of ionization, one particular response occurs.

Radiated electromagnetic waves on plasma will absorb, scatter or pass through. We can choose to absorb, scatter or pass through with changing the basic parameters like electron density and collision frequency [4]. The relative permittivity of plasma is defined by [6]:

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

where ω_p is plasma frequency, ω is operating frequency and υ is collision frequency. One must distinguish the difference between the 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. Plasma frequency is equal to [3]:

$$\omega_p = \sqrt{\frac{4\pi n_e e^2}{m_e}} \tag{2}$$

where n_e is electron density, e is the charge of electron and m_e is the electron mass. The electron density is defined by [7]:

$$n_e = \frac{J}{e\sqrt{\frac{kT_e^{\circ}}{m_e}}} \tag{3}$$

where J is current density, k is Boltzmann's constant and T_e is electron temperature which is calculated for the fluorescent lamps [7].

The boundary conditions at a dielectric-vacuum interface are that the normal component of the displacement and tangential component of the electric field be continuous. These conditions are satisfied at the plasma-air boundary. Satisfaction of the boundary conditions gives the potential inside the plasma in terms of the incident amplitude and frequency and it is shown that the field in the plasma becomes large (resonant) when the frequency is [3]:

$$\omega = \frac{\omega_p}{\sqrt{2}} \tag{4}$$

Since the plasma column is in resonance at (4), the electrons in the column oscillate in response to the driving electric field. This motion reradiates, or scatters, the incident field in cylindrical waves. Since the motion of the electrons in the plasma is largest at resonance, the scattered power will be a maximum at resonance.

In the case of $\omega > \omega_p$, propagation constant(γ) as shown in (5) becomes imaginary and the wave will propagate. However, if $\omega < \omega_p$, the propagation constant becomes real and the wave will not propagate[3].

$$\gamma = \alpha + j\beta = jk_0\sqrt{\mu_r\varepsilon_r} \tag{5}$$

III. Design and Implementation

A. Simulation

For the simulation of a plasma antenna we need the plasma frequency and collision frequency. The collision frequency of fluorescent lamps has been calculated between $10^6 Hz < \upsilon < 10^9 Hz$ [7]. But for the plasma frequency we need the electron density which is shown in (3). So we can now define the plasma material with these two parameters.

We simulate a 0.5 meter fluorescent tube with a cylindrical coupler as shown in Fig.1.

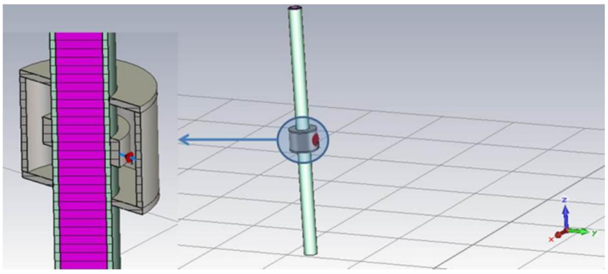

Fig.1: Simulated plasma antenna in CST with cylindrical coupler

For this fluorescent tube the electron density is chosen to be 5×10^{17} [7]. Hence, from (2) the plasma frequency is 59.4×10^9 Hz. We define a plasma material with the calculated plasma frequency with a glass material around it and assume $\upsilon = 5\times10^8$ Hz. Then for the coupling, we design a ring with a thickness of 0.005 meter at the center of the lamp and shield it with an outer cylinder and put a feed port between the ring and outer cylinder.

Based on what have been mentioned above, the S_{11} parameter of simulated plasma antenna is shown in Fig.2.

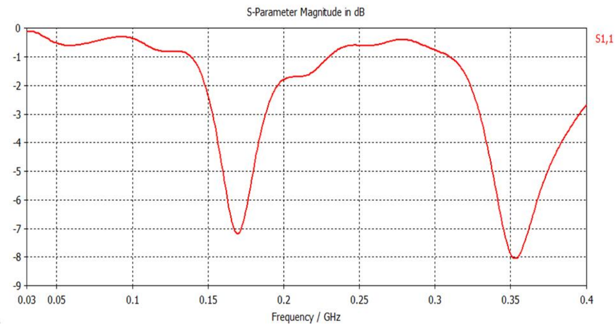

Fig.2: S11 parameter magnitude of plasma antenna between 30-400MHz in dB

Obviously, frequencies with S_{11} under -5dB are resonance frequency. These frequencies are detected to be 170MHz and 352MHz. Fig.3 shows the far field pattern of the plasma antenna at 170MHz.

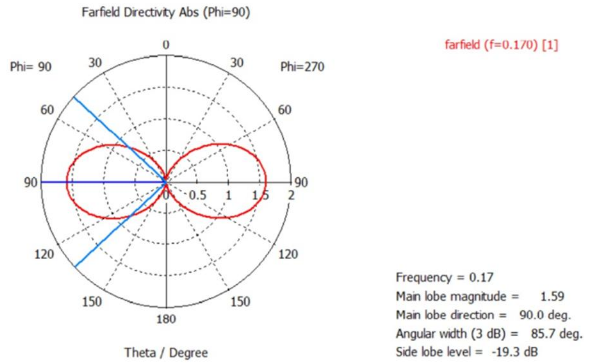

Fig.3: Far-field pattern of the plasma antenna in 170MHz in linear scaling in a polar plot

The maximum directivity of the antenna is 2.45 dB and the pattern of the antenna is broadside. This antenna has a considerable Side Lobe Level (SLL) of -19.3 dB.

C. *Implementation*

In order to validate the simulations, an experiment procedure is needed. For this purpose, we use a 0.5 meter fluorescent tube with 20W power, same as the one simulated. We build a cylindrical coupler of Aluminum that has a ring inside and an outer cylinder. And finally for the robustness of the antenna, we build an F-shape leg as shown in Fig.4.

Fig.4. Implemented plasma antenna with F-shape leg and cylindrical coupler

As we have mentioned in Section II, first the plasma antenna must be ionized. We decided to ionize the tube with AC driven voltage using a variable voltage transformer (Variac) before the fluorescent transformer to have the control on AC driven voltage between 0-300V. As shown in Fig.5 with increasing the voltage, the lamp is on or ionized. In addition, the amount of ionization of the lamp is also important because all the parameters can be changed.

Fig.5: Ionization of the plasma antenna with Variac and transformer

Now we connect the SMA port on the coupler, which is soldered to the ring inside, to the Spectrum Analyzer and with transmitting a signal from Helix antenna, we can see the received signal on it. In this work, because of the structure of the coupler, there is no electromagnetic interference (EMI) and the outer cylinder is acting like a shield. We connect the Helix antenna to a power source and propagate a signal between 0-180MHz in space. Fig.6 shows the connection between the coupler and Spectrum Analyzer before the test.

Fig.6. Connection of the antenna and Spectrum Analyzer before the test

The designed plasma antenna received the signal at 140MHz with the largest magnitude. According to Fig.2 there is a resonance at 170MHz but our received signal is at 140MHz as shown in Fig. 7. This 30MHz difference is because of the loss in transmitter antenna, cable and others. The frequency range in Spectrum Analyzer is between 50-150MHz with the 10MHz span.

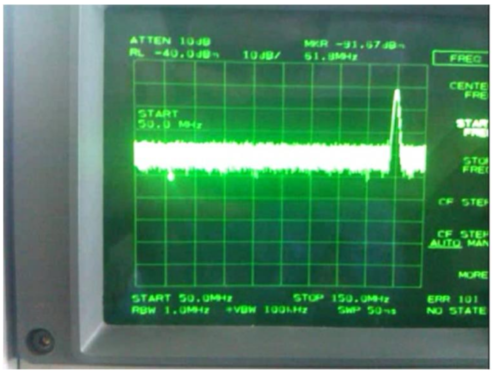

Fig.7 Result of the receiving signal from Helix Antenna with Plasma Antenna in Spectrum Analyzer.

V. Conclusion

The simulation and experimental implementation of a Plasma antenna was applied and the results which are obtained by both procedures meet to a good agreement. For a simulation of a dispersive environment like plasma we need a basic theory of parameters which have been assigned in the paper. Building this kind of antennas needs a suitable coupler to protect from the EM interference. This kind of antenna has so many advantages than metal antennas and many abilities in high frequencies and electronic warfare which can be considered for future works.

References

[1] A Seminar Presentation on Plasma Antenna under guidance of: Noorine Fatima. Presented by: Rishabh Chaturvedi. Roll NO-16 EC 9/26/2011

[2] Plasma Technology and Its Applications in Material Processing-K.Srinivasan-IIM METAL NEWS,Vol 12 No.2,April 2009

Books:

[3] Theodore Anderson, 2011. Plasma Antennas. Artech House

Papers from Conference Proceedings:

[4] Alexeff, I., T. Anderson, S. Parameswaran, E. P. Pradeep, J. Hulloli, and P. Hulloli, \Experimental and theoretical results with plasma antennas," *IEEE Transactions on Plasma Science*, Vol. 34, No. 2, 2006.

[5] H.Q.YE, M.Gao and Chang J. Tang. Radiation Theory of the Plasma Antenna. IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 59, NO. 5, MAY 2011

[6] W.Jiayin, Sh.Jiaming, W.Jiachun, Xu Bo. 2006. Study of the Radiation Pattern of the Unipole Plasma Antenna. IEEE conf, ISAPE, International Symposium.

[7] K.H.Loo, Member, IEEE, Graham J. Moss, Richard C. Tozer, Senior Member, IEEE, David A. Stone,Masafumi Jinno, Member, IEEE, and Robin Devonshire. 2004. A Dynamic Collisional-Radiative Model of A Low-Pressure Approach to Modeling Fluorescent Lamps for Circuit Simulations. IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL 19, NO.4