Basic Features of Plasma Antennas for Applications in Electronic Warfare

Wellington Guilherme da Silva[1] and Homero Santiago Maciel[1]
1 Technological Institute of Aeronautics, Department of Physics – ITA, 12228-900, CTA , São José dos Campos, SP, Brazil.

Abstract — **Plasma antennas refer to several antenna concepts that use some ionized medium. Plasma antennas are reconfigurable, stealthy and resistant to jamming and EMP (Electromagnetic Pulse) weapons. These special characteristics do plasma antennas useful in electronic warfare applications. This work presents a basic survey on plasma antennas for application in electronic warfare. Fundamental plasma physics theory, current plasma antenna designs and electronic warfare applications are presented.**

Keywords — **electronic warfare, plasma antennas, plasma physics.**

I. INTRODUCTION

The term plasma antenna has been applied to a wide variety of antenna concepts that incorporate some use of an ionized medium [1]. It is not a new concept, since last century there are studies on similar uses and the first patent about this application was registered in 1919 [2]. A plasma medium is a good conductor because it contains ionized particles (ions and electrons), and therefore plasma filaments can be used instead of metal parts, thus it can serve as transmission line, reflectors and antennas [1].

Plasma antenna has been developed to work in the range of 100 MHz to 10 GHz as well as a metal antenna [3] [4]. Furthermore, plasma antennas have some advantages over metal antennas as low RCS [4]. Furthermore, when a jamming signal strikes an energized plasma antenna, and if the plasma frequency is sufficiently low, the incident signal simply passes through the plasma antenna without interaction or reflection [3]. Thus, these special characteristics do plasma antennas useful in electronic warfare applications.

However, plasma antenna designs are complex due to plasma physic phenomenon. Plasma can be established in free air, at atmospheric pressure, or inside tube containing a specific gas, at low pressure, like neon or argon. Before starting plasma antenna discussion it is necessary to understand the basic on plasma physics. After this initial approach, we will be shown the mains characteristics on plasma antenna designs and a comparison with metal antennas.

II. DEFINITIONS ON PLASMA PHYSICS

Lewi Tonks and Irving Langmuir, in 1920, were the firsts to apply the term plasma to describe the inner region of a glow discharge. The word plasma has its origin from Greek and means something moldable.

Silva W.G., welsilva@ita.br, Tel. +55-12-3947-5940; Maciel, H. S., homero@ ita.br, Tel. +55-12-3947-5934.

In general plasma contains neutral particles, electrons, ions, excited particles and photons. Understanding the complex behavior of plasmas has led researchers to formulate the fundamental equations of plasma physics. Research on plasmas has led to important advances in fields as diverse as microelectronics, lighting, waste handling, space physics, medicine and lasers between others applications. There is an important plasma property called quasi-neutrality, i.e., the amount of positive and negative particles are balanced [5]. Another important characteristic of plasma is the collective effects; it is due to the long range of electromagnetic forces each charged particle in the plasma interacts simultaneously with a considerable number of the other charged particle [5]. The simplest plasma example is the lighting devices as fluorescent and neon bulbs lights. Some experiments on plasma antenna use simple fluorescent light bulbs as plasma antenna or plasma reflector.

Plasma differs from ordinary gas in several points [6]:

- Highly chemical activation;
- Electrical conductivity;
- High energy and high temperature (gas and electron); and
- Electromagnetic radiation and light emission.

For plasma antenna designs, an important point is the plasma conductivity. Plasma has electrical conductivity because it has many charged particles (electrons and ion), thus it is affected by electric and magnetic fields, and the electric current can pass there. Below there are some important concepts on plasma physics

1) Breakdown Voltage:

The breakdown voltage depends on the product of the gas pressure and the electrode separation. This fact was studied carefully by Paschen (1889) [7], what has become known as Paschen's Law. According to (1) Vb depends, besides on the product pd, on the A and B constants which are characteristics of the gas type, see Table 1, but also depends on the γ which is the secondary electron emission coefficient which depends on the gas type and electrode material [8].

$$V_b = \frac{Bpd}{\ln \dfrac{Apd}{\ln(1+1/\gamma)}} \quad (1)$$

Table 1 The Constants A and B to be used in connection with Equation (1) [8].

Gas	A Ionizations/cm-Torr	B V/cm-Torr	E/p Validity Range V/cm-Torr
Air	15	365	100-800
N2	12	342	100-600
H2	5.1	138.8	20-600
He	3	34	20-150
Ne	4	100	100-400
Ar	14	180	100-600
Kr	17	240	100-1000
Xe	26	350	200-800

2) Ionization Degree: The degree of ionization α is defined as $\alpha = n_i/(n_i + n_a)$ where n_i is the number density of ions and n_a is the number density of neutral particles. Plasmas can be classified according to the degree of ionization [6].

- Fully ionized Plasma: When α > 90%, in these cases the neutral particles have litlle effect on the plasma;
- Partilay ionized plasma: When 1% < α < 90%, It has middle character of fully ionized plasma and weakly ionized plasma;
- Weakly ionized plasma: The α < 1%, effects of electrons are dominant.

3) Plasma Frequency: An important plasma property is the stability of its macroscopic space charge neutrality. When a plasma is instantaneously disturbed from the equilibrium condition, the resulting internal space charge fields give rise electrical field that tend to restore original charge neutrality. This effect is characterized by a natural frequency of oscillation known as plasma frequency which depends on the electron density according to (2) [5].

$$\omega_p = \sqrt{\frac{n_e e^2}{m_e \varepsilon}} \qquad (2)$$

Where:

n_e electron density
e electron charge
m_e electron mass
ε permittivity of free space

4) Plasma conductivity: It is another important character to plasma antenna. The plasma conductivity depends on electrons density (n_e) and collision frequency (υ_c), and is defined by (3) [9].

$$\sigma = \frac{e^2 n_e}{m_e \upsilon_c} \qquad (3)$$

Substituting (2) in (3) is possible to define another expression for plasma conductivity according to (4). Thus, the plasma conductivity is related to the plasma frequency.

$$\sigma = \frac{\varepsilon \omega_p^2}{\upsilon_c} \qquad (4)$$

A number of other important plasma parameters should be mentioned, however it is not the goal of this paper to deeply describe these concepts. For this purpose suitable text book are suggested in references.

III. PLASMA GENERATION

Artificially generated plasma can be classified on the basis of the generation methods. Among many plasma generation methods, the following classifications can be considered roughly:

- Electrical discharge plasma;
- Microwave-induced plasma;
- Shock wave-induced plasma;
- Magneto hydrodynamic (MHD)-induced plasma;
- High energy particle beam (electron-ion)-induced plasma;
- Combustion-induced plasma; and
- Laser-induced plasma.

These are some methods to transfer energy to neutral particles in order to produce ionized particles (ions and electrons). In order to generate plasma, the electron must be removed from the neutral gas particle, by ionizing collision. Fig. 1 presents an illustration of an electrical discharge plasma in which an electrical field is used to transfer kinetic energy to electrons which subsequently transfer energy to neutral particles by inelastic collisions thus generating electron-ion pairs. The electrons, in its way to high potential electrode (anode), perform successive ionization collisions that result in an avalanche effect which, in appropriate conditions, lead to plasma generation [8].

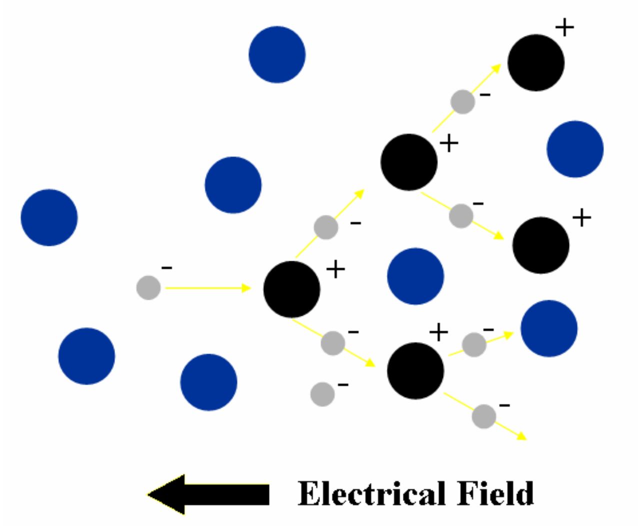

Fig. 1 – Plasma generation using electrical field.

The simplest method for plasma generation is using a gas filed tube containing a noble gas like neon or argon.

IV. PLASMA ANTENNA DESIGNS

Plasma can be used as a reflector element or as antenna instead of metal conductor. Plasma antenna can be generated at low pressure or atmospheric pressure [1]. Three important plasma antenna parameters are:

- Time required for complete ionization;
- Decay time; and
- Plasma frequency.

The decay time, once the excitation is removed, is due to recombination process, for example when a positive ion attaches free electron and it turns a neutral particle. Typically decay times are on the order of tens to hundreds of microseconds [1].

A. Plasma reflectors

A plasma sheet can be used instead of a metal sheet as the reflecting surface [10, 11], see Fig. 2. Therefore the reflections occur within the plasma instead of boundary between free space and surface as they do in metal reflector. There is a pseudo surface named “critical surface” that appears somewhere inside of the plasma. A high quality plasma reflector must have a critical surface that can be consistently reproduced and is stable during operation [1]. The time necessary to stabling and decaing the critical surface, in order of 10 microseconds, have been achieved. At frequencies below the plasma frequency, the plasma is a good reflector [1].

Fig. 2 – Plasma reflector [1].

Plasma reflector antenna shows lower sidelobes than metal reflector antenna, see Fig. 3 [12].

B. Plasma Antennas

The simplest plasma antenna is essentially linear antennas using ionized gas instead of metal conductors. In Fig. 4 a plasma antenna is used for receiving radio FM and AM waves to radio receiver. When the density of plasma in the tube is high, the antenna works in FM. In the lower density the antenna works in both FM and AM [13]. This is due to the fact that plasma antennas attenuate electromagnetic waves below the plasma frequency [1], i.e., plasma antenna is a high pass filter [14].

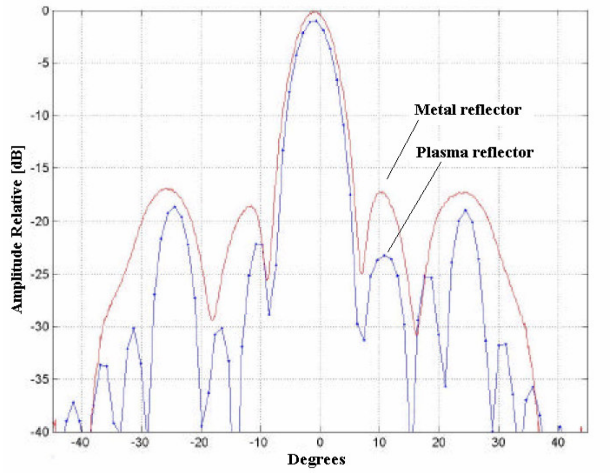

Fig. 3 – Plasma reflector [1].

Fig. 4 – A plasma antenna connected to a radio [13].

Plasma antennas were constructed out of a commercial fluorescence light tube filled with low pressure Ar gas with minor amount of Hg. When the plasma antenna is on, it works like a metal antenna, when it is off, there is only weakly reflections from glass tube, hence a very low RCS (Radar Cross Section) [14]. Plasma antennas are resistant to jamming. When a jamming signal strikes an energized plasma antenna, and if the plasma frequency is sufficiently low, the incident signal simply passes through the plasma antenna without interaction or reflection. Plasma antenna noise level in both the receiving and transmitting modes was comparable to the metal antenna [3].

IV. CONCLUSIONS

Plasma antenna is comparable to the metal antennas, but it presents special characteristics useful in electronic warfare. **First:** Plasma antennas are reconfigurable, i.e., when one plasma antenna is turned off the antenna turns a dielectric, this characteristic is useful to mounting reconfigurable antenna arrays. **Second:** Plasma antennas are stealthy, i.e., presents low RCS (Radar Cross Section) when it is turned off its RCS drops 20 dB. **Third:** Plasma antennas are resistant to jamming. When a jamming signal strikes an energized plasma antenna, and if the plasma frequency is sufficiently low, the incident signal simply passes through the plasma antenna without interaction or reflection [3]. Futhermore, plasma antenna presents low sidelobes, which is secondary lobes jamming resistant.

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