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Plasma Antenna

N M Vijay
(Electronics and Instrumentation Engineering) ,R.M.D. Engineering college, Tamil Nadu, India

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Abstract
The fundamental base of plasma antenna is the use of an ionized medium as a conductor. The plasma antenna is a radiofrequency antenna formed by a plasma columns, Filaments or sheets, which are excited by a surface wave. The relevance of this device is how rapidly it can be turned on and off, only applying an electrical pulse. Besides its wide carrier frequency, the great directivity and controllable antenna shape. Otherwise a disadvantage is that it needs energy to be ionized. There are studies to reduce this power to ionize and maintain the plasma tube with higher plasma densities and frequencies.

I. Plasma Antenna Theory

Radiated Power P_{rad} :

To calculate the characteristic of the plasma antenna is used the fluid models. We consider a center-fed dipole with a triangular current distribution along the z direction and we only contemplate one dimension for simplicity. The momentum equation and continuity equation in plasma for the electrons is: $m(\frac{dv}{dt}+\nu\nu) = -e\ (Ee^{-j\omega t} - \nabla\phi)$ and $\frac{dn}{dt} + n_o\frac{dv}{dz} = 0$, where m is the electron mass, ν is the electron velocity, v is the collision rate, e is the electron charge, E is the electric Field, w is the frequency in radians, ϕ is the electric potential and no is the background plasma density. If we combine them: $n_0 = \frac{jnoe}{\omega(v-j\omega)}\left\{\frac{dE}{dz} - \frac{d2_\phi}{dz^2}\right\}$. Using the Gauss's Law $\frac{d2_\phi}{dz^2} = \frac{en}{\varepsilon}$ where $\varepsilon = \frac{1-\omega_p 2}{\omega(\omega-j\omega)}$ is the dielectric constant in the plasma and wp $= \sqrt{\frac{ne^2}{\mathcal{E}om}}$ is the dielectric constant in the plasma and $\omega_p = \sqrt{\frac{ne^2}{\varepsilon om}}$ the plasma frequency, we obtain the dipole momentum: p=$\sigma \frac{enoEod}{2m\omega(\omega+jv)-\omega_p 2}$ where d is the length of the antenna and σ is the cross section. We can obtain the radiated power as: $P_{rad} = \frac{k^2\omega^2}{12\pi\varepsilon oc}|P|^2$ where k = $\frac{2\pi}{\text{wavelength}}$ is the wave number. Thus the radiated power depends on the plasma frequency and collision rate:

$$P_{rad} = \frac{\epsilon o}{48\pi c}(kd)^2\omega_{p^2}\frac{(\omega Eo)^2}{[(\omega^2-\omega_p^2)^2 + v^2\omega^2]}$$

II. Electromagnetic waves in plasma antenna

In the plasma antenna there are two mechanism to radiate. One is as the produced by the current oscillation on the surface of a metal antenna and is caused by the disturbing currents on the interface between plasma and medium. This one is called m-radiation. The other, d-radiation, is produced by EM wave transmission and is like the radiation of dielectric antenna. The d-radiation modes excite the interface disturbing currents between plasma and medium, meanwhile these latter in uence the transmission modes. The Figure 2 is a schema of the wave propagation in the diferent mediums. We have to consider a geometry like in the Figure 1, corresponding to a tube.

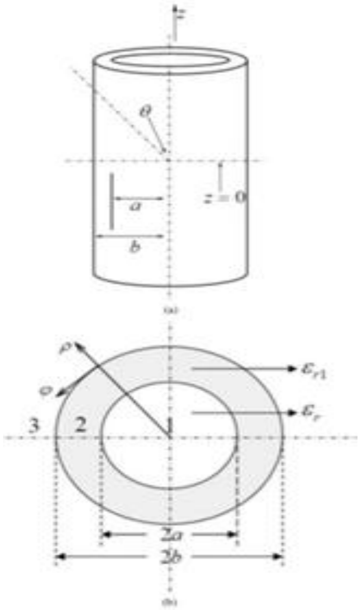

Figure 1: The model of a plasma antenna.

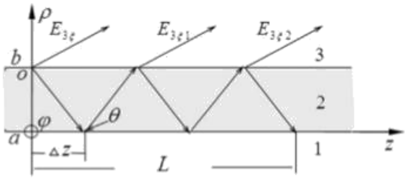

Figure 2: Plasma mirrors. Left: using a laser. Right: using a chamber (tube).

Radiation modes and transmission modes are both simultaneously in some frequency bands when a homogeneous EM wave goes into a plasma antenna. While the frequency of the EM waves raises, the radiation modes go appearing, however the transmission modes are only in particular frequency bands, then it is possible to control them changing the frequency of the EM waves and another parameters.

The EM wave of transmission modes are attenuated along the plasma antenna, hence the disturbing currents excited by transmission modes also decay.

III. Ionization

Applying enough voltage in the electrodes the gas can be ionized or with an EM held. In the following pictures are shown closed tubes of gas excited by electrodes.

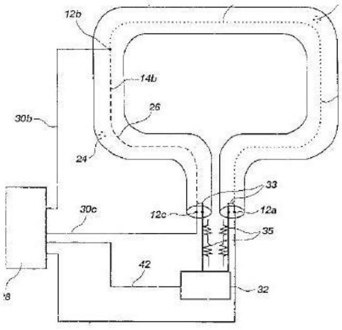

Figure 3: Loop Antenna

There is a design that permets an easily reconfiguration by different plasma path, each one in a different frequency band. Besides the gas can be ionizated also by laser or by high power microwave beams. On the other hand, a design with only one electrode allows to reduce the scattering and the interferences. For this, it may be use the radiated or received EM field to feed and support structure. The electric field excites a surface wave , this one is propagated along the walls of the tube and ionize the gas.

IV. Generation and Containment of Plasma

The container for the plasma can be in an envelopment or in free space. The gases that can be used to compose the plasma are neon, xenon, argon, krypton, hydrogen, helium and mercury vapor. The electrodes, microwaves, fiber optics, RF heating, lasers or EM couplers are used to apply power to the plasma. The tube containment require more than one contact for energizing the plasma, and this is a clearly disadvantage. Then to apply the ionizing potential there is another option, a surface wave from a single end. At one end of the plasma tube is emitted and it deformates the plasma surface, turning out the surface charge layer. There is a device designed to ionize a plasma column called Surfatron. We can find another options as helicon wave and others. The ionization time and decay time are important parameters. The decay time is dictated by the recombination rate, the typical times are on the order of tens to hundreds of microseconds.

V. Reflectors

In this section are described the reflectors that use plasma elements. If the frequency is lower than the plasma frequency, the plasma behaves as a reflector and the EM waves are attenuated. Plasma can be a good absorber when EM waves go into the plasma medium. This characteristic has been exploited in the design of plasma radar absorbing material for stealth application. The reflection occurs at a critical surface inside of the plasma. The interesting of this is the rapid inertia-less two dimensional scanning, frequency selectivity and potential wideband frequency performance. The reflector can be create by a laser beam and optics using a sequence of line discharges forming a sheet of plasma. The Figure 4 shows a schema of plasma mirror.

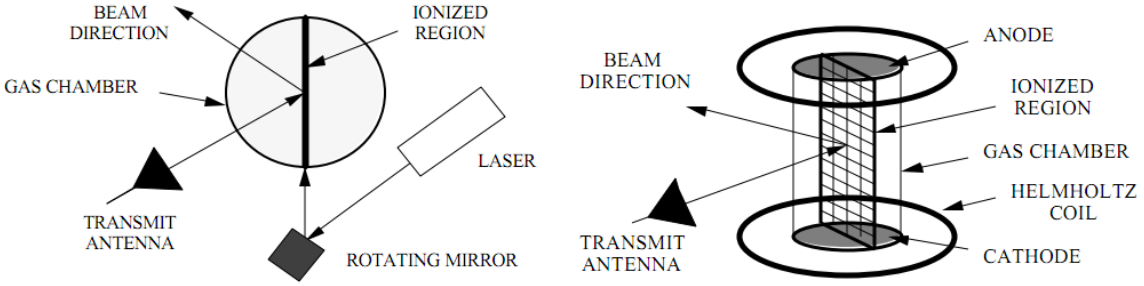

Figure 4: Plasma mirrors. Left: using a laser. Right: using a chamber (tube).

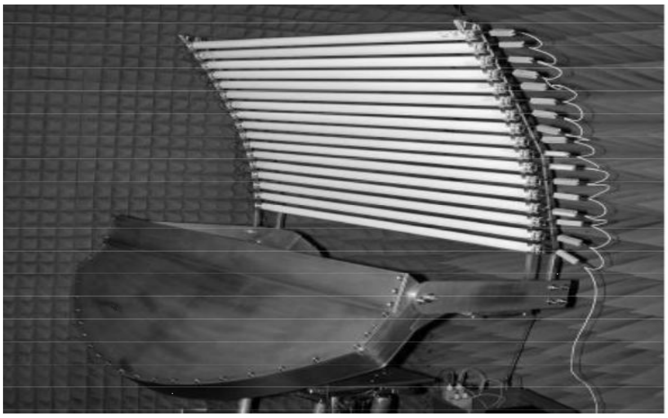

Figure 5: Plasma reflector.

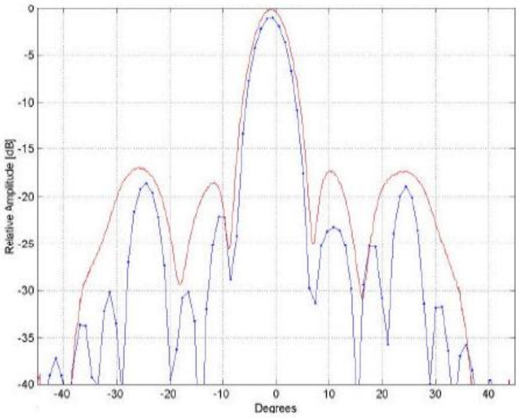

Figure 6: Comparison of radiation pattern from plasma (blue) and metal (red)

In the Figure 6 we can observe that the plasma pattern has a better directivity, and the side lobe level(NLPS) is also better in the plasma pattern.

VI. Plasma antenna windowing

The Plasma antenna windowing consists in a RF signal transmitted through a plasma tubes, these tubes are off in plasma density that permet RF signals pass through. The design consists in a reconfigurable antenna comprised of a linear omni directional antenna and a cylindrical shell of conducting plasma around it. The plasma shield consists of a set of tubes with gas that upon electrification forms plasma, fluorescent light bulbs are used. The plasma acts as a reflector for frequencies smaller than the plasma frequency. If all of the tubes of the shield are electrified, the radiation is trapped inside. Then if you remove one or more tubes in a non electrified state, the radiation can escape and there is an aperture. The way to open and close an aperture is as easily as apply voltage or not. Figure 7 shows the configuration of the plasma shield with an aperture.

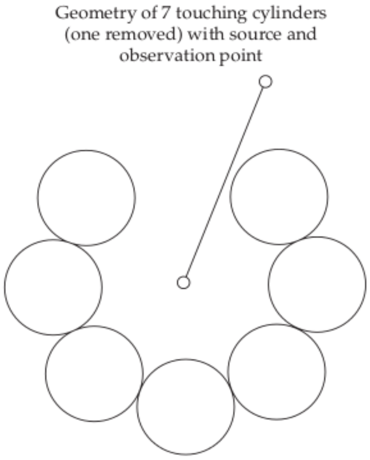

Figure 7: Plasma window antenna consisting of seven touching cylinders

VII. Applications

The plasma antenna has military applications for its stealth, weight and easily reconfiguration ipboard/submarine antenna replacements. Among other applications are:

[1] . Unmanned air vehicle sensor antennas
[2] . IFF ("identification friend or foe") land-based vehicle antennas
[3] . Stealth aircraft antenna replacements
[4] . Broad band jamming equipment including for spread-spectrum emitters
[5] . ECM (electronic counter-measure) antennas.
[6] . Phased array element replacements.
[7] . EMI/ECI mitigation
[8] . Detection and tracking of ballistic missiles
[9] . Side and backlobe reduction
[10] The commercial applications comprise:
[11] Telemetry
[12] Broad-band communications
[13] Ground penetrating radar
[14] Navigation
[15] Weather radar
[16] Wind shear detection and collision avoidance

VIII. Conclusion

The plasma antennas has an ability to revolutionize communication sector and a number of researches are being conducted to utilize plasma as a successful fourth state of matter. The ionization process is the factor that pulls it down but still with certain advents of new technology it is now possible to maximize plasma output. The Plasma antenna finds its best use in army fields. Still it is dead sure that these substances are a vital components for our tomorrow’s world.

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