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Analysis of Plasma Antenna

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ABSTRACT: A plasma antenna represents a completely new technology of antennas that relies on plasma elements rather than in traditional metallic wires or surfaces. The feasibility of a plasma antenna is provided by plasma conductivity, that is given by free electrons obtained by gas ionization with the application of an intense electromagnetic field; the main advantage of plasma antennas results from the possibility of changing electromagnetically their parameters: this characteristic provide a plasma antenna with peculiar properties that make it suitable for several applications (e.g. stealth application, antenna arrays, smart antennas, frequency selective shields). The pump signal and gas discharge parameters have to be carefully chosen in order to optimize plasma antenna design and realization, in particular discharge working conditions have to be defined in order to obtain the desired antenna properties in terms of efficiency, effective length and so on.

To this purpose a self-consistent numerical model of electromagnetic field-plasma interaction mechanism have been developed: a preliminary one-dimensional model was firstly implemented allowing the numerical approach to be validated, then a cylindrical configuration enabled a more realistic description of plasma antenna behavior with respect to the working conditions adopted. At the same time experimental characterizations has been carried out to propose some measurement set-up and experimental procedures to characterize the pump and radiated signal networks and investigate how plasma state is affected by them.

KEYWORDS: plasma antenna, traditional, characteristic, cylindrical

I. INTRODUCTION

The plasma state is a characterization of matter where long range electromagnetic interactions dominate the short range inter-atomic or intermolecular forces among a large number of particles. Plasma replaces a solid conductor which is widely used in the current radio antennas. Highly ionized plasma is a good conductor and thus it is used as transmission line for guiding waves. Neutral molecules can be separated into positive ions and negative ions using ionization process which helps in generation of plasma. Electrons are much lighter than positive ions and neutral ions. Thus electrons are considered to be moving through stationary fluid of ions and neutrals with some friction. The propagation characteristics of electromagnetic (EM) waves in a uniform ionized medium can be inferred from the equation of motion of a single “typical” electron. Such a medium is called “cold plasma.”

Plasma antenna is usually driven by radio frequency (RF) power, when the insulated tube filled with inert gas is discharged thus the plasma is created. The RF power is propagated between plasma and tube in surface wave mode, and the plasma column is also sustained by the energy of surface wave. The plasma has the properties which make it can be used as conducting medium; Plasma can be rapidly created through applying bursts of RF power to discharge the inert gas, and the plasma antenna can be rapidly switched on and off in microsecond, when it is off, it behaves like a dielectric material, when it is on, plasma can be used as the conductor, therefore, the power supplied ionizes the gas providing the conductive medium for the signal to be radiated , so it also can be applied as the conducting medium for propagating the RF signals; in plasma antenna application two signals are needed: the pump signal that creates and sustains the plasma column, and the signal to be radiated that has to be coupled to the plasma element. As known that plasma is a kind of dispersion medium, its electric parameters e.g., conductivity and permittivity are no longer the constant, parameters of the plasma mentioned above will be changed according to the plasma frequency, strength of driven power, the coupling methods and location of the power coupling on plasma antenna, etc.

Its parameters e.g., surface current distribution, radiation pattern, gain, conductivity and wave vector are entirely

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determined by the particle interactions of the plasma, and the dynamic movements of particles in plasma are governed by the external electrical fields, which make the plasma antenna have reconfigurable properties. Reconfigurable methods of plasma antenna can be developed and obtained through related experiments and analysis[3].

PLASMA

Plasma is one of the four fundamental states of matter, the others being solid, liquid, and gas. A plasma has properties unlike those of the other states.A plasma can be created by heating a gas or subjecting it to a strong electromagnetic field, applied with a laser or microwave generator at temperatures above 5000 Celsius. This decreases or increases the number of electrons, creating positive or negative charged particles called ions, and is accompanied by the dissociation of molecular bonds, if present.

The presence of a significant number of charge carriers makes plasma electrically conductive so that it responds strongly to electromagnetic fields. Like gas, plasma does not have a definite shape or a definite volume unless enclosed in a container. Unlike gas, under the influence of a magnetic field, it may form structures such as filaments, beams and double layers. Plasma is the most abundant form of ordinary matter in the Universe (of the forms proven to exist; the more abundant dark matter is hypothetical and may or may not be explained by ordinary matter), most of which is in the rarefied intergalactic regions, particularly the intracluster medium, and in stars, including the Sun. A common form of plasma on Earth is produced in neon signs.

BASIC ANTENNA:

Antennas can be designed to transmit and receive radio waves either in all horizontal directions equally (Omni directional antennas) or preferentially in a particular direction (Directional or high gain antennas). Traditional metallic antenna consists of metallic conductors, electrically connected (often through a transmission line) to the receiver or transmitter. An oscillating current creates an oscillating magnetic field around the antenna elements. These time varying fields radiate away from the antenna into space as a moving transverse electromagnetic wave. Conversely, during reception, the oscillating electric and magnetic fields of an incoming radio wave exert force on the electrons in the antenna elements causing them to move back and forth, creating oscillating currents in the antenna. Antennas are characterized by a number of performance measures which a user would be concerned with in selecting or designing an antenna for a particular application. Two major factors associated with the design of antennas are the antenna resonant point or center operating frequency and the antenna bandwidth or the frequency range over which the antenna operates. Other parameters are gain, directivity, radiation efficiency, return loss and VSWR[1].

PLASMA ANTENNA :

Unlike traditional metal antenna, plasma antenna is based on partially or fully ionized gas used as a conducting material . A plasma antenna is made up of column of ionized gases in which free electrons emit, reflect and absorb the radio signals as free electrons in a metal antenna. Argon, Krypton and Xenon gases are used in Plasma tube because these are chemically inert and don't attack the Plasma tube and electrodes. Plasma antenna can be energized by any of non-thermal generation techniques. Main advantage of plasma antenna is that they are highly reconfigurable antennas as ionized gas can be easily switched ON and OFF at any time interval to make a phase shift in an array. This feature makes it suitable to perform beam steering in very short time (millisecond) and provide degrees freedom at wider range of beam steering angle covering the 0 to 360deg span [1].

II. LITERATURE SURVEY

Physically, an antenna is an arrangement of one or more conductors, usually called elements. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field. In reception, the inverse occurs. An electromagnetic field from another source induces an alternating current in the elements and a corresponding voltage at the antenna's terminals. Some receiving antennas (such as parabolic and horn types) incorporate shaped reflective surfaces to collect the radio waves striking them, and direct these waves onto the actual conductive elements. Some of the first rudimentary antennas were built in 1888 by Heinrich Hertz (1857-1894) in his pioneering experiments to prove the existence of electromagnetic waves predicted by the theory of James Clerk Maxwell. Hertz placed the emitter dipole at the focal point of a parabolic reflector. The words antenna (plural: antennas) and aerial are used interchangeably, but usually a rigid metallic structure is termed an

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antenna and a wire format is called an aerial.

HISTORY:

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, now called plasma, in 1879. Plasma is by far the most common form of matter. Plasma in the stars and in the tenuous space between them makes up over 99% of the visible universe and perhaps most of that which is not visible. Important to ASI's technology, plasmas are conductive assemblies of charged and neutral particles and fields that exhibit collective effects. Plasmas carry electrical currents and generate magnetic fields. When the Plasma Antenna Research Laboratory at ANU investigated the feasibility of plasma antennas as low radar cross-section radiating elements, Red Centre established a network between DSTO ANU researchers, CEA Technologies, Cantec Australasia and Neolite Neon for further development and future commercialization of this technology. The plasma antenna R & D project has proceeded over the last year at the Australian National University in response to a DSTO (defense Science and Technology Organization) contract to develop a new antenna solution that minimizes antenna detectability by radar. Since then, an investigation of the wider technical issues of existing antenna systems has revealed areas where plasma antennas might be useful.

The paper attracts the interest of the industrial groups involved in such diverse areas as fluorescent lighting, telecommunications and radar. Plasma antennas have a number of potential advantages for antenna design. When a plasma element is not energized, it is difficult to detect by radar. Even when it is energized, it is transparent to the transmissions above the plasma frequency, which falls in the microwave region. Plasma elements can be energized and de–energized in seconds, which prevents signal degradation. When a particular plasma element is not energized, its radiation does not affect nearby elements. HF CDMA Plasma antennas will have low probability of intercept (LP) and low probability of detection (LPD) in HF communications.

Material processing by chemically active plasmas has been used as a basic tool in the manufacturing industry worldwide (Lieberman, 2005). Plasma-based techniques for surface modification present the great advantage of controlling surface features up to the nanometer scale. Material fabrication in thin film form, plasma-immersion ion implantation (PIII) (Anders, 2000), and plasma etching for lithography or just surface cleaning are the main processes that make plasma treatment so attractive in the field of materials science. Deposition of protective coatings and films with optical and/or electric performance are examples of the versatility of plasma techniques. Large-scale fabrication of integrated circuits in the electronic industry has benefited from the development of plasma technology. Other involved industries are aerospace, automotive (Lampe, 2003), steel and biomedical (Hauert, 2004). Table 1.1 is a summary of some current plasma applications. A wide variety of plasmas can be generated with a broad spectrum of properties with the size and detail shape of the plasma source determined by its respective applications (Hippler et al, 2001). Technical plasmas are generated mostly by the electrical breakdown of a neutral gas in the presence of an externally excited electrical field

DEVELOPMENT PROCESS

Initial investigations were related to the feasibility of plasma antennas as low-radar cross-section radiating elements with further development and future commercialization of this technology. The plasma antenna R&D project has proceeded to develop a new antenna solution that minimizes antenna-detectability by radar at the first instance. But since then an investigation of the wider technical issues of existing antenna systems has revealed areas where plasma antennas might be useful.

A significant progress has been made in developing plasma antennas. Present plasma antennas have been operating in the region of 1 to 10 GHz. Field trials have shown that an energized plasma reflector is essentially as effective as a metal reflector. However, when deenergized, the reflected signal drops by over 20 dB. Still some technicalities related to plasma antennas like increasing the operating plasma density without overloading the plasma discharge tubes, reducing the power required and the plasma noise caused by the ionizing power supply, etc have to be looked into in order to make them the useful technologies for wireless communication in near future.

The future of high-frequency, high-speed wireless communications could very well be plasma antennas capable of

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transmitting focused radio waves that would quickly dissipate using conventional antennas. Thus, plasma antennas might be able to revolutionize not just high-speed wireless communications but also radar arrays and directed energy weapons. The good news is that plasma antennas will be on-the-shelf in the next couple of years. The bad news is that some military powers can use it to create a more advanced version of its existing pain beam.

III. PLASMA ANTENNA TECHNOLOGY

Since the discovery of radio frequency ("RF") transmission, antenna design has been an integral part of virtually every communication and radar application. Technology has advanced to provide unique antenna designs for applications ranging from general broadcast of radio frequency signals for public use to complex weapon systems. In its most common form, an antenna represents a conducting metal surface that is sized to emit radiation at one or more selected frequencies. Antennas must be efficient so the maximum amount of signal strength is expended in the propagated wave and not wasted in antenna reflection. Plasma behaves as a reflector if the frequency is lower than the plasma frequency. 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. Plasma reflectors can be created using laser and optics using a sequence of line discharges forming a sheet of plasma. Plasma Reflector is shown in Figure 1

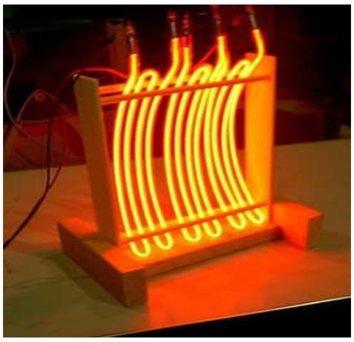

Fig 1 Plasma Reflector

Fig. 2 Ionized Gas Plasma Antenna

Plasma antenna technology employs ionized gas enclosed in a tube (or other enclosure) as the conducting element of an antenna. This is a fundamental change from traditional antenna design that generally employs solid metal wires as the conducting element. Ionized gas is an efficient conducting element with a number of important advantages. Since the gas is ionized only for the time of transmission or reception, "ringing" and associated effects of solid wire antenna design are eliminated. Figure 2 shows ionized gas plasma antenna. The design allows for extremely short pulses, important to main forms of digital communication and radars. The design further provides the opportunity to construct an antenna that can be compact and dynamically reconfigured for frequency, direction, bandwidth, gain and beam width. Plasma antenna technology will enable antennas to be designed that are efficient, low in weight and smaller in size than traditional solid wire antennas.

We also believe our technology can compete in many metal antenna applications. Our initial efforts have focused on military markets. General Dynamics' Electric Boat Corporation sponsored over $160,000 of development in 2000 accounting for substantially all of our revenues. Initial studies have concluded that a plasma antenna's performance is equal to a copper wire antenna in every respect. Plasma antennas can be used for any transmission and/or modulation technique: continuous wave (CW), phase modulation, impulse, AM, FM, chirp, spread spectrum or other digital techniques. And the plasma antenna can be used over a large frequency range up to 20GHz and employ a wide variety of gases (for example neon, argon, helium, krypton, mercury vapor and zenon). The same is true as to its value as a receive antenna.

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1 WORKING

In plasma antenna, ionized gas is being enclosed in the tube and the gas acts as the conducting material of the antenna. When this gas is ionized to a plasma state it becomes conductive replacing the metals which were used in traditional antenna. The plasma antenna generates localized concentrations of plasma to form a plasma mirror which deflects a Radio Frequency (RF) beam. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature [1].

CLASSIFICATION OF PLASMA ANTENNA

Gas Plasma Antenna - A gas is ionized to create plasma. (Frequency range up to 90GHz.) It consists of ionized gas enclosed in a discharged tube. When supply is given to the tube, the gas inside it gets ionized to plasma. Plasma has very high electrical conductivity, so it is possible for radio frequency signals to travel through them to radiate radio waves, or to receive them. Fig 3 shows ionized gas plasma antenna.

Solid State Plasma Antenna - Plasma is formed due to cloud of electrons. (Frequency range 1-300GHz.). Figure 3 shows structure of solid-state plasma antenna.

A plasma for solid state antenna can be created in two ways –

- Solid state plasma antenna can be made from silicon wafer by first thermally oxidizing the surfaces and subjecting the wafer to a high temperature stabilization process.
- Alternatively, an array of PIN diodes may be formed on the surface and may be forward biased to create the desired plasma. At high enough electron density each cloud of electron generated by diodes reflects high frequency radio waves like a mirror.

Fig 3 Ionized gas plasma antenna

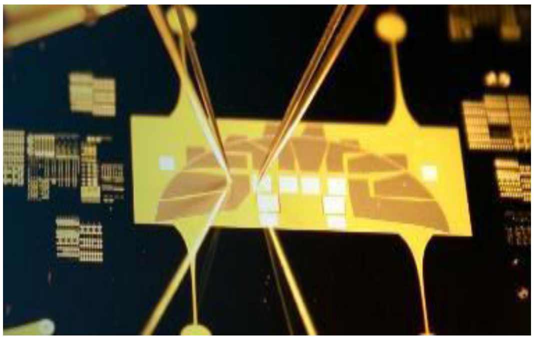

Fig 4 solid state plasma antenna

Unique Characteristics of Plasma

- Plasma antenna provides increased accuracy and reduces computer signal processing.
- After a gas is ionised, the plasma antenna has virtually no noise floor.
- A single dynamic antenna structure can use time multiplexing so that many RF subsystems can share many antenna resources reducing the number and size of antenna structures.
- Plasma resonance, impedance and electron charge density are dynamically reconfigurable.
- Our plasma antenna can transmit and receive from the same aperture provided that the frequencies are widely separated.

Features of Plasma Antenna

Ringing effect which was a problem associated with a regular antenna is due to the traditional metal elements which reduces its capabilities in high frequency short pulse transmission. But in plasma antenna the antenna gets de-ionized by sending a pulse and thus the problem of ringing effect is overcome. Another feature of plasma antenna is that it can easily communicate signals in very short pulses and also it has the ability to focus a single beam [1]. This feature is useful in areas of digital communication and radar.

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1. Higher power- This can be achieved in the plasma antenna than in the corresponding metal antenna because of lower Ohmic losses. Plasmas have a much wider range of power capability than metals.
2. Enhanced bandwidth- By the use of electrodes or lasers the plasma density can be controlled. The theoretical calculations on the controlled variation of plasma density in space and time suggest that greater bandwidth of the plasma antenna can be achieved than the corresponding metal antenna of the same geometry. This enhanced bandwidth can improve discrimination.
3. Higher efficiency and gain-Radiation efficiency in the plasma antenna is higher due to lower Ohmic losses in the plasma. Standing wave efficiency is higher because phase conjugate matching with the antenna feeds can be achieved by adjusting the plasma density and can be maintained during reconfiguration
4. Lower noise - The plasma antenna has a lower collision rate among its charge carriers than a metal antenna and calculations show that this means less noise
5. Perfect reflector- When the plasma density is high the plasma becomes a loss-less perfect reflector. Hence there exist the possibilities of a wide range of lightweight plasma reflector antennas.

Unique Characteristics of a Plasma Antenna

One fundamental distinguishing feature of a plasma antenna is that the gas ionizing process can manipulate resistance. When demonized, the gas has infinite resistance and does not interact with RF radiation. When demonized the gas antenna will not backscatter radar waves (providing stealth) and will not absorb high-power microwave radiation (reducing the effect of electronic warfare countermeasures). A second fundamental distinguishing feature is that after sending a pulse the plasma antenna can be demonized, eliminating the ringing associated with traditional metal elements. Ringing and the associated noise of a metal antenna can severely limit capabilities in high frequency short pulse transmissions. In these applications, metal antennas are often accompanied by sophisticated computer signal processing. By reducing ringing and noise, we believe our plasma antenna provides increased accuracy and reduces computer signal processing requirements. These advantages are important in cutting edge applications for impulse radar and high-speed digital communications. Based on the results of development to date, plasma antenna technology has the following additional attributes:

- No antenna ringing provides an improved signal to noise ratio and reduces multipath signal distortion.
- Reduced radar cross section provides stealth due to the non-metallic elements.
- Changes in the ion density can result in instantaneous changes in bandwidth over wide dynamic ranges.
- After the gas is ionized, the plasma antenna has virtually no noise floor.
- While in operation, a plasma antenna with a low ionization level can be decoupled from an adjacent high-frequency transmitter.
- A circular scan can be performed electronically with no moving parts at a higher speed than traditional mechanical antenna structures.
- It has been mathematically illustrated that by selecting the gases and changing ion density that the electrical aperture (or apparent footprint) of a plasma antenna can be made to perform on par with a metal counterpart having a larger physical size.
- Our plasma antenna can transmit and receive from the same aperture provided the frequencies are widely separated.
- Plasma resonance, impedance and electron charge density are all dynamically reconfigurable. Ionized gas antenna elements can be constructed and configured into an array that is dynamically reconfigurable for frequency, beam width, power, gain, polarization and directionality on the fly.
- A single dynamic antenna structure can use time multiplexing so that many RF subsystems can share one antenna resource reducing the number and size of antenna structures.

IV. DESIGN OF ANTENNA & SIMULATION OF RADIATION PATTERN

To enhance the application of plasma antenna, different configuration of glass tubes or discharge tube have been constructed and studied as plasma reflectors and plasma window. Recently it is found that plasma structure can be transformed into different geometries. Experimental attempts have been made to demonstrate that the different plasma structures can be used in wireless communication. This study devotes our attention on simulation of radiation pattern of reconfigurable plasma antenna and results are matched with experiments. The paper is composed as, section gives

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design of single plasma antenna, section deals with simulation of single plasma antenna, section provides design of array plasma antenna, section presents the simulation results of array plasma antenna, section gives the comparison between single and array plasma antenna and at the end section is the conclusions of the study[4].

DESIGN OF SINGLE PLASMA ANTENNA

A design of experimental set-up of plasma antenna is shown in Fig.5. In this et-up, a 30 cm long glass tube with diameter of 3 cm is evacuated by a combined system of rotary and diffusion pumps. The system is than filled with argon gas to various working pressure. A capacitive coupler with width of 35 mm is mounted 2 mm above the ground plate with diameter of 120 mm and thickness of 20 mm at one end of the glass tube. The initial breakdown takes place inside the tube in the gap between coupler and ground plate by a CW RF generator operated at a frequency of 5 MHz and power of up to 100 watts. The gap can be varied from 1 mm to 5 mm. Hence A 30 cm long plasma column can be formed in the glass tube. it may be quite interesting to study discharge mechanism for the formation of 30 cm long plasma column while RF power is fed at one end of the glass tube.

The initial breakdown takes place in the discharge tube close to the gap in the field applicator. The gap is varied from 0.5 mm to 5 mm and the required power for initial breakdown varies from 10 watts to 20 watts. The potential difference between both should be more than 300 volts. Due to the field gradients within the gap region in field applicator, electrons are driven along the tube axis by the pondermotive force. The length of plasma column varies from 5 cm to 30 cm when input power increases from 5 watts to 36 watts, with all other operating parameters being constant. In such measurements, typical plasma electron density and temperature are 5x1010cm-3 and 2.5eV respectively. Axial plasma density profile indicate negative density gradient (dn(z)/ dz< 0) of plasma, which is also an intrinsic feature ofthe discharges sustained with surface waves in a travelling mode. In addition radial density profile indicates that plasma density is maximum at the center of the plasma column while it falls with the radial distance from the center towards the inner surface of the glass tube. Radiation from plasma antenna can be calculated with the help of axial and radial plasma density distribution.

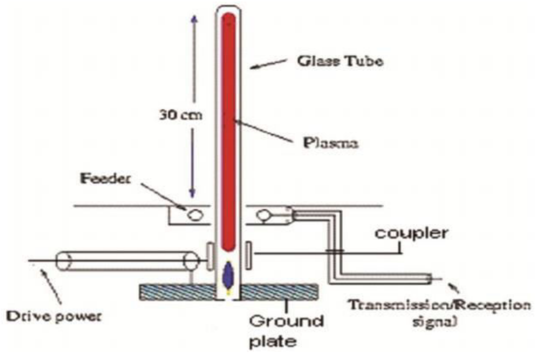

Fig 5 Design of Plasma antenna

The system dimension is much less than the wavelength (R << λ, L << λ) where R is the diameter of 3 cm and L is the length of plasma antenna of 30 cm. the length of plasma column can be controlled by input power and working pressure.

SIMULATION OF SINGLE PLASMA ANTENNA

The field or power patterns of an antenna are important parameters to estimate the directivity and half power beam width (HPBW) of the antenna. The software is used for simulation is HFSS (High Frequency Structure Simulator), is a commercial finite element method solver for electromagnetic structures from Ansys. It is one of several commercial tools used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging. HFSS is used to study the radiation pattern of plasma antenna. With the help of 3D modular a geometrical model of object is designed as described in the previous section and shown in Fig 6. The conductivity and dielectric constant of the plasma are calculated and assigned as the material properties. Although there is no method for

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directly measuring the conductivity, it can be calculated using other parameters. Plasma is a conducting medium and its electric conductivity can be calculated by the formula given below.

$$\sigma = e\ 2ne\vartheta m\ (\omega 2 + \vartheta m\ 2\ )$$

Calculated by ne (plasma density ~ 1016 m -3), ω(wave frequency ~30x106 Hz) and ϑm (collision frequency ~4x108 Hz). The value of , ω and ϑm given in the brackets were measured in experiment at a working pressure of 0.05 mbar.It may be quite interesting to formulate the electric conductivity with the antenna length to generalize the antenna properties. Hence, an attempt is made to write an equation of electric conductivity with antenna length using the values from the above outlined calculations and given by $\sigma = 22.5 - (0.75)h$.

The equation $\varepsilon p = 1 - \omega pe\ 2\ (\omega -)$ is used to calculate the dielectric constant of the plasma. After assigning the material properties 3-D boundary and ports are designed as shown in Fig.6. Solution is obtained for the operating frequency 5 MHz.

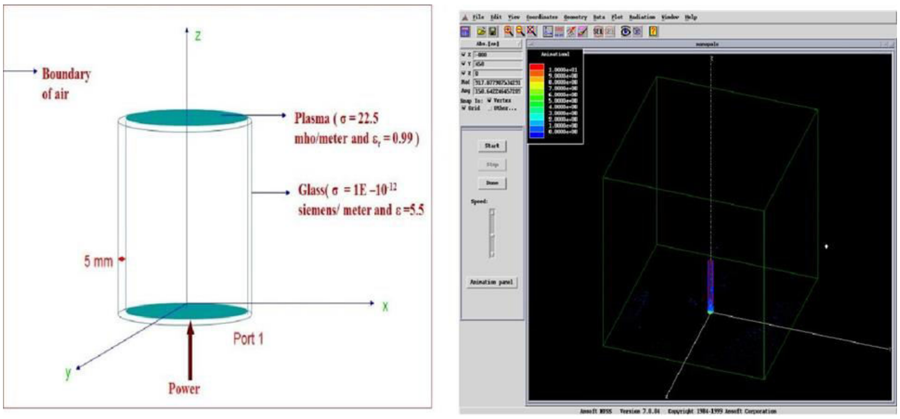

Fig 6 Simulation conditions of plasma antenna and Picture of the real simulation

Simulation results are obtained for elevation and azimuthal power pattern which are shown in Fig. 7 and Fig 8. The intensity of power can be determined by the color code.

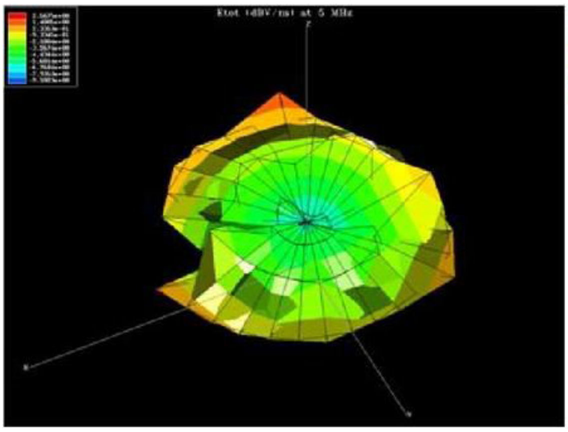

Fig.7 Elevation power pattern

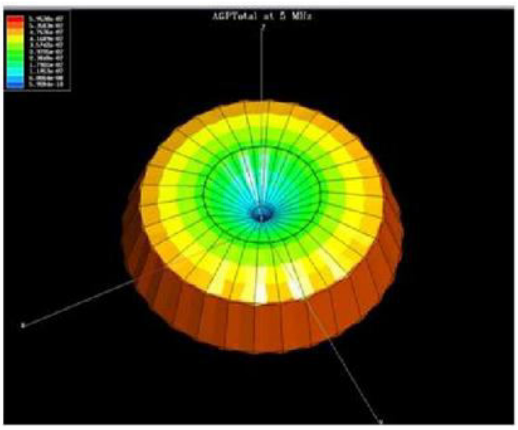

Fig.8 Azimuthal power pattern

For better understanding of plasma antenna parameters, experiments are also conducted. Hence, a set of experiments

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are carried out to measure the power patterns of a fundamental frequency of 5 MHz, and then with the help of measurements, directivity and HPBW are also estimated. In the contrary to conventional methods for studying radiation power patterns of the plasma antenna, an isotropic receiving antenna (radiation level meter) is moved at different angles of elevation and azimuthal plane in the far field region and power density is measured. Spherical geometry (r, θ, φ) is used to define the elevation and azimuthal plane. In the sequence of experiments, firstly, the elevation power pattern is measured in the elevation plane (y-z plane) where the azimuthal angle and radial distance are kept constant while the elevation angle is varied. The elevation power patterns of the plasma antenna are measured by moving the receiving antenna in an arc over the plasma antenna with a 15-degree increment in a range of $90° < \theta < 270°$ at different vertical planes having a 15-degree increment in the horizontal plane. A normalized elevation power pattern is shown in Fig.8. In this experiment, it is assumed that the power pattern should be symmetric in the upper and lower vertical planes of the plasma antenna.

Hence, it can be concluded that the maximum power is radiated at $\theta = 90°$ and $\theta = 270°$ or perpendicular to the axis of the antenna and radiated power is minimum at $\theta = 0°$ and $\theta = 180°$ or parallel to the axis of the antenna. Consequently, in the second experiment, the azimuthal power patterns are measured in the x-y plane of the plasma antenna keeping both the elevation angle and radial position of the receiving antenna constant. Power patterns are measured by moving the receiving antenna in the horizontal plane with an increment of 15 degrees of $0° < \theta < 360°$ at different heights (5 cm, 10 cm and 15 cm) from the source end of the plasma antenna. The normalized power patterns are shown in Fig.9. It can be seen in the figure that the power patterns are symmetric around the axis of the plasma antenna. Thus, findings of this study indicate that this plasma antenna can be considered as a monopole antenna. Moreover, directivity is estimated with the help of the power patterns of the plasma antenna using the conventional method. Directivities of the plasma antenna is calculated in both planes (azimuthal and elevation) separately and both the values are added to get total directivity. It has been observed so far that the azimuthal power pattern is symmetric around the antenna axis, which indicates that directivity of the plasma antenna in azimuthal plane (D_θ) should be one. Directivity in elevation plane (D_φ) is also calculated with the help of the elevation power pattern, which has been studied previously as the maximum power density radiates to the perpendicular of the antenna axis ($\theta = 90°$) and minimum power density radiates to the parallel of the antenna axis ($\theta = 0°$). Apparently, a typical value of directivity in the elevation plane is calculated as nearly 1.75. Therefore, total directivity of the plasma antenna is calculated by the addition of both values of directivities ($D_\theta + D_\varphi$), which is 2.75. Simulation and experimental results are similar which also indicate that single plasma column works as a monopole wire antenna.

DESIGN OF ARRAY PLASMA ANTENNA

Surface wave driven plasma column (single plasma antenna) is transformed into finite number of small cylindrical stationary striations or plasma blobs by changing the operating parameters such as working pressure (0.03 to 1 0 mbar), drive frequency (3 to 10 MHz), input power (40 to 60 W), radius of glass tube (1.5 o 2.5 cm), length of plasma column (5 to 30 cm), and background gas (argon, air, helium, and oxygen). Its worthwhile to mention here that certain combinations of operating parameters can transform a plasma column into striations. All striations are arranged in the axis of glass tube. Each cylindrical striation is a very short cylindrical plasma column, which is very similar to a point radiating source. Hence, each striation can act as an antenna, which can be called as radiating element or antenna element arranged in an array along the axis of the antenna (z-axis of glass tube). Therefore, entire structure can be treated as an assembly of antenna elements or array plasma antenna. A photo of array plasma antenna is shown in Fig. 9. In this figure, six antenna elements are shown in series in 30 cm long plasma column at input power of 50 W and working pressure of 0.03 mbar. A design for simulation of such plasma antenna is constructed as shown in Fig.10.

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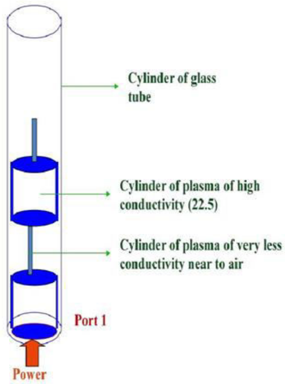


Fig. 9 Photo of array plasma antenna Fig. 10 Array plasma antenna for simulation

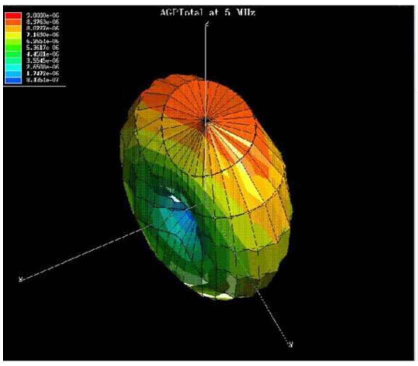
Simulation Result of Array Plasma Antenna

Before going to simulation, we design the array of plasma antenna, let us find out the conductivity, phase relation and mathematical understanding of array of plasma antenna. It may be quite interesting to formulate the electric conductivity with antenna length to generalize the antenna properties. Hence, an attempt is made to formulate an equation for electric conductivity with antenna length using the values from above outlined calculations, which is given below –

$h = 22.5^{-0.75h} \cos\ h\ h$

Where h is the height of plasma antenna from the bottom. So far, it has been demonstrated that current, potential, and conductivity profiles are quite similar and amplitudes show presence of antenna elements. HFSS simulation is performed for the array plasma antenna (as shown in Fig 10). Elevation and azimuthal power pattern are obtained and results are shown in Fig. 11 and Fig. 12 respectively.

Simulation results have to match with experimental results. For this purpose, set of experiments are conducted to measure the power patterns of a fundamental frequency of 5 MHz, then with the help of measurements, directivity is will be estimated. In this experiment, power patterns in different planes (elevation and azimuthal) are measured by isotropic receiving antenna, (radiation level meter) in the far field region of the plasma antenna. Spherical geometry (r, and φ) is use to define the elevation and azimuthal plane. Measurements are obtained by moving the, receiving antenna in different planes keeping fixed position of plasma antenna. In the sequence of experiments, first, the elevation power pattern is measured in the elevation plane (y-z plane), where azimuthal angle and radial distance are kept constant.



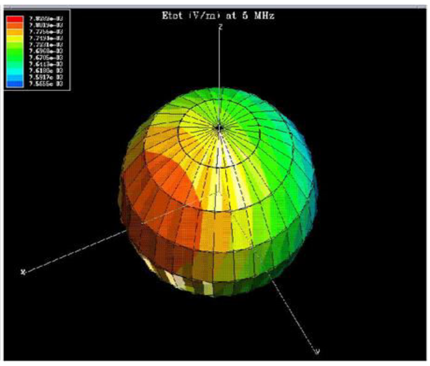


Fig.11 Elevation power pattern Fig.12 Azimuthal power pattern

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The elevation power patterns of plasma antenna are measured by moving the receiving antenna in an arc over the plasma antenna with 15° increment from 90°<θ<270° at different vertical planes having 15° increment in the horizontal plane. A normalized elevation power pattern is shown in Fig.10. In this experiment, it is assumed that power pattern should be symmetric in upper and lower vertical planes of plasma antenna. Hence, it can be concluded that the maximum power is radiated at θ=90° and 270° or perpendicular to the axis of antenna and radiated power is minimum at θ =0° and 180° or parallel to axis of antenna. This result suggests that antenna elements are arranged in such a way so that entire structure can be treated as broadside array plasma antenna. Consequently, in the second experiment, the azimuthal power patterns are measured in the x-y plane of the plasma antenna keeping constant elevation angle and radial position of receiving antenna. Power patterns are measured by moving the receiving antenna in horizontal plane with an increment of 15° of 0°<θ<360° at different heights (5, 10, and 15 cm) from the source end of the plasma antenna. A normalized power pattern is shown in Fig.10. Results indicate that power patterns are symmetric around the axis of the plasma antenna. Moreover, directivity is estimated with the help of power patters of the plasma antenna. Generally, directivity of an antenna is equal to the ratio of the maximum power density to its average value over a sphere as observed in the field of an antenna. Directivities of plasma antenna are calculated in both planes (azimuthal and elevation) separately and added both the values to get total directivity. It has been investigated so far that azimuthal power patter is symmetric around the antenna axis which indicates that directivity of plasma antenna in azimuthal plane (D_θ) should be one. Directivity in elevation plane (D_φ) is also calculated with the help of elevation power pattern, which has been studied previously as the maximum power density radiates to the perpendicular of the antenna axis (0 =90°) and minimum power density radiates to the parallel of antenna axis (θ =0°). Apparently, a typical value of directivity in the elevation plane is calculated as nearly 3.1.

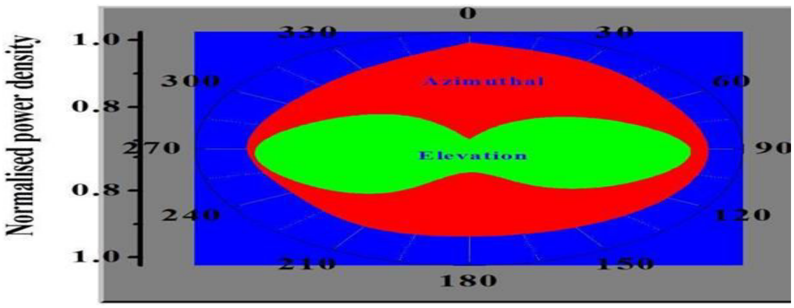

Fig. 13 Measured elevation and azimuthal power pattern of the array plasma antenna

Therefore, total directivity of plasma antenna is calculated by the addition of both values of directivities (D_φ+D_θ), which is 4.1. The maximum power density is measured to the perpendicular to the antenna axis (θ=90°) and minimum to the antenna axis (θ=0°). Moreover, it is desirable to study the directivity of an array antenna with number of antenna elements, hence an experimental attempt is made to examine the directivity of this array plasma antenna with different number of antenna elements. In this experiment, number of antenna elements is varied by tuning the operating parameters, as discussed above, and directivity is estimated with the measurements of power patterns. This study yields that directivity increases with the number of antenna elements. It increases from 2.9 to 4.1 while antenna elements are varied from 4 to 10 in the 30 cm long plasma antenna. This study invokes an interesting application of our array plasma antenna over the conventional metallic array antenna that directivity can be controlled in an array plasma antenna by operating parameters. Outlined simulation and experimental studies on power patters and directivity reveal that the maximum power is radiated in the direction perpendicular to the antenna axis of our array plasma antenna.

Comparison of Monopole and Array Antenna

Comparison of power patterns and directivity of monopole and array plasma antenna is carried out and measurements are shown in Fig. 13 and Fig. 14 respectively. Results suggest that array plasma antenna (directivity = 4.5) is more directive than the single (monopole) plasma antenna (directivity = 2.5).

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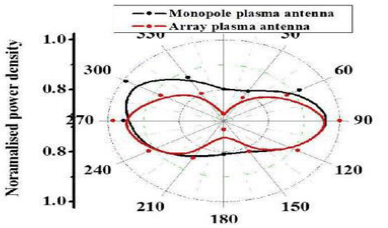

Fig.14 Comparison of power patterns

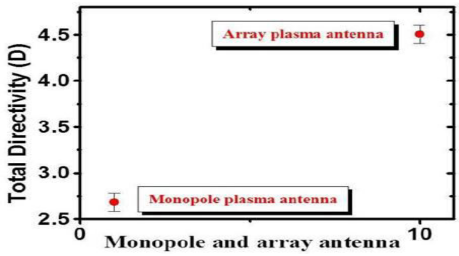

Fig.15 Comparison of directivity

V. CONCLUSION

The principle behind the working of the plasma antenna is same as the normal conventional antennas. Only the solid metal conductor is replaced with the plasma. This plasma gives it many advantages over the current antennas. It is more efficient, fast and also can be manufactured cheaply. There might be some disadvantages associated with plasma antennas but those can be overcome. It will take some time for plasma antennas to be commercially available, but it will change the landscape of antennas when it is available for use.

A 30 cm long plasma antenna is excited at the one end by using surface wave. With the help of HFSS, radiation patterns of single plasma antenna are obtained and matched with the experimental results. By changing the operating parameters single plasma antenna are transformed into array of small radiation elements, is called array plasma antenna. Therefore such antenna is called reconfigurable plasma antenna as it can be transformed its geometry. Simulation and experimental study indicate that array plasma antenna is more directive than the single plasma antenna. Hence our study explores the radiation pattern of a reconfigurable plasma antenna.

Plasma Silicon Antennas hold much promise in the field of mobile communications. They are electronically steerable and beam forming, two traits that allow for more precision and higher data transfer rates. They are made from silicon, a common element in the Earth's crust, as opposed to today's metal antennas that need less abundant elements such as copper and aluminum to be manufactured. Additionally, silicon can be produced without emission of fossil fuels, unlike aluminum. A PSiAN's denser beam means not only more data transmitted but also an increase in the supportable user base, meaning telecommunications companies can build fewer antennas and save money. The potential of Plasma Silicon Antennas is great, and their future use in mobile communications looks bright.

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