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## Chapter I

## Introduction

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, Redcentre established a network between DSTO ANU researchers, CEA Technologies, Cantec Australia 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 (Defence 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 project 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.

## Chapter II Overview of plasma technology

Antenna design has been an integral part of virtually every communication and radar application .Antenna represents a conducting metal surface that is sized to emit radiation at one or more selected frequencies .This technology employs ionized gas enclosed in a tube and also employs solid metal wires as the conducting element."Ringing" and associated effects of solid wire antenna design are eliminated.

When gas is charged, it becomes conductive, allowing radio frequency (RF) signals to be transmitted or received. Also its performance is equal to a copper wire antenna in every respect and It can be used over a large frequency range up to 20GHz and it can employ a wide variety of gases .



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 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. The design allows for extremely short pulses, important to many 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.

When gas is electrically charged, or ionized to a plasma state it becomes conductive, allowing radio frequency (RF) signals to be transmitted or received. We employ ionized gas enclosed in a tube as the conducting element of an antenna. When the gas is not ionized, the antenna element ceases to exist. This is a fundamental change from traditional antenna design that generally employs solid metal wires as the conducting element. We believe our plasma antenna offers numerous advantages including stealth for military applications and higher digital performance in commercial applications. 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 xenon). The same is true as to its value as a receive antenna.

## Chapter IV Market applications of plasma technology

Plasma antennas offer distinct advantages and can compete with most metal antenna applications. The plasma antenna's advantages over conventional metal elements are most obvious in military applications where stealth and electronic warfare are primary concerns. Other important military factors are weight, size and the ability to reconfigure. Potential military applications include:

- Shipboard/submarine antenna replacements.
- Unmanned air vehicle sensor antennas.
- IFF ("identification friend or foe") land-based vehicle antennas.
- Stealth aircraft antenna replacements.
- Broad band jamming equipment including for spread-spectrum emitters.
- ECM (electronic counter-measure) antennas.
- Phased array element replacements.
- EMI/ECI mitigation
- Detection and tracking of ballistic missiles
- Side and backlobe reduction

Military antenna installations can be quite sophisticated and just the antenna portion of a communications or radar installation on a ship or submarine can cost in the millions of dollars.

Plasma antenna technology has commercial applications in telemetry, broad-band communications, ground penetrating radar, navigation, weather radar, wind shear detection and collision avoidance, high-speed data (for example Internet) communication spread spectrum communication, and cellular radiation protection.

One fundamental distinguishing feature of a plasma antenna is that the gas ionizing process can manipulate resistance. When deionized, the gas has infinite resistance and does not interact with RF radiation. When deionized 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 deionized, 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, beamwidth, 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.

To date, plasma antenna technology has been studied and characterized by ASI Technology Corporation revealing several favorable attributes in connection with antenna applications. The work was carried out in part through two ONR sponsored contracts. NCCOSC RDTE Division, San Diego, awarded contract N66001-97-M-1153 1 May 1997. The major objective of the program was to determine the noise levels associated with the use of gas plasma as a conductor for a transmitting and receiving antenna. Both laboratory and field-test measurements were conducted.

The second contract N00014-98-C-0045 was a 6-month SBIR awarded by ONR on November 15, 1997. The major objective of this effort was to characterize the GP antenna for conductivity, ionization breakdowns, upper frequency limits, excitation and relaxation times, ignition mechanisms, temperatures and thermionic noise emissions and compare these results to a reference folded copper wire monopole. The measured radiation patterns of the plasma antenna compared very well with copper wire antennas.

ASI Technology Corporation is under contract with General Dynamics Electric Boat Division and in conjunction with the Plasma Physics Laboratory at the University of Tennessee, an inflatable plasma antenna is being developed. This antenna is designed to operate at 2.4 Ghz and would be mounted on the mast of an attack submarine. In addition a prototype plasma waveguide and plasma reflector has been designed and demonstrated to General Dynamics.

The following discussion illustrates why there is military and government support for plasma antenna concepts. The gas plasma antenna conducts electron current like a metal and hence can be made into an antenna but with distinct advantages. The following technological concepts are important to plasma antennas:

1. **Higher power** - Increased power 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 as evident from low powered plasma in fluorescent bulbs to extremely high-powered plasmas in the Princeton University experimental fusion reactors. In this range, a high-powered plasma antenna is still low powered plasma. Since plasmas do not melt, the plasma antennas can provide heat and fire resistance. The higher achievable power and directivity of the plasma antenna can enhance target discrimination and track ballistic missiles at the S and X band.
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. EMI/ECI - The plasma antenna is transparent to incoming electromagnetic signals in the low density or turned off mode. This eliminates or diminishes EMI/ECI thereby producing stealth. Several plasma antennas can have their electron densities adjusted so that they can operate in close proximity and one antenna can operate invisible to others. In this physical arrangement mutual side lobe and back lobe clutter is highly reduced and hence jamming and clutter is reduced.

4. 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. Estimates indicate a 20db improvement in antenna efficiency.

5. Reconfiguration and multifunctionality - The plasma antenna can be reconfigured on the fly by controlled variation of the plasma density in space and time with far more versatility than any arrangement of metal antennas. This reduces the number of required elements reducing size and weight of shipboard antennas. One option is to construct controlled density plasma blankets around plasma antennas thereby creating windows (low-density sections of the blanket) for main lobe transmission or reception and closing windows (high-density regions in the plasma blanket). The plasma windowing effect enhances directivity and gain in a single plasma antenna element so that an array will have less elements than a corresponding metal antenna array. Closing plasma windows where back lobes and side lobes exist eliminates them and reduces jamming and clutter. This sidelobe reduction below 40db enhances directivity and discrimination. In addition, by changing plasma densities, a single antenna can operate at one bandwidth (e.g. communication) while suppressing another bandwidth (e.g. radar).

6. 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.

7. 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.



The advantage of a plasma antenna is that it can appear and disappear in a few millionths of a second. This means that when the antenna is not required, it can be made to disappear, leaving behind the gas – filled column that has little effect on the electromagnetic fields in the proximity of the tube. The same will be true for fiber glass and plastic tubes, which are also under consideration.

The other advantage of plasma antenna is that even when they are ionized and in use at the lower end of the radio spectrum, say HF communications, they are still near transparent to fields at microwave frequencies.

The same effect is observed with the use of ionosphere, which is plasma. Every night amateur radio operators bounce their signals off the ionosphere to achieve long distance communications, whilst microwave satellite communication signals pass through the ionosphere.

- Reduced RCS
- Reduced interference and ringing
- Can change shape to control pattern and bandwidth
- Can change plasma parameters
- Glow discharge increased
- visible signature \*
- Good RF coupling for electrically small antennas
- Frequency selectivity
- Stable and repeatable
- Efficient
- Flexibility in length and direction of path

As part of a “blue skies” research program, DSTO has teamed up with the ANU’s Plasma Research Laboratory to investigate the possibility of using plasmas like those generated in fluorescent ceiling lights, for antennas

The research may one day have far reaching applications from robust military antennas through to greatly improved external television aerials. Antennas constructed of metal can be big and bulky, and are normally fixed in place. The fact that metal structures cannot be easily moved when not in use limits some aspects of antenna array design. It can also pose problems when there is a requirement to locate many antennas in a confined area.

Weapons System Division has been studying the concept of using plasma columns for antennas, and has begun working in collaboration with ANU plasma physicists Professor Jeffrey Harris and Dr. Gerard Borg. Work by the team has already led to a provisional patent and has generated much scientific interest as it is so novel. It offers a paradigm shift in the way we look at antennas and is already providing the opportunity to create many new and original antenna designs

Plasma is an ionized gas and can be formed by subjecting a gas to strong electric or magnetic fields. The yellow lights in streets are a good example of plasmas though a better example is the fluorescent tubes commonly used for lighting in homes.

The type of plasma antenna under investigation is constructed using a hollow glass column which is filled with an inert gas. This can be ionized by the application of a strong RF field at the base of the column. Once energized, the plasma column can be made to exhibit many of the same characteristics of a metal whip antenna of the type mounted on most cars. The metal whips that may be considered for a plasma replacement are anywhere from a few centimetres to several metres long.

There are many potential advantages of plasma antennas, and DSTO and ANU are now investigating the commercialization of the technology. Plasma antenna technology offers the possibility of building completely novel antenna arrays, as well as radiation pattern control and lobe steering mechanisms that have not been possible before. To date, the research has produced many novel antennas using standard fluorescent tubes and these have been characterized and compare favourably with their metal equivalents. For example, a 160 MHz communications link was demonstrated using plasma antennas for both base and mobile stations. Current research is working towards a robust plasma antenna for field demonstration to Defence Force personnel.

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