Smart Plasma Antenna as an RFID Reader with Built-in Protection against EMI

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Abstract— The smart plasma antenna [1]-[4] based on opening and closing antenna windows to create antenna beam steering. It can steer 360 degrees in the azimuthal direction and 180 degrees in the z direction. The smart plasma antenna RFID reader can scan and read both passive and active RFID tags. Furthermore the smart plasma antenna is very compact compared to a phased array because plasma physics is used to steer and shape the antenna beam. The smart plasma antenna can easily fit in a small room where tags are to be read. It meets most SWaP criteria. The smart plasma antenna can have an omnidirectional metal antenna along the central axis such as a dipole or biconical antenna and is surrounded by a cylindrical ring of plasma tubes to shape and steer the antenna beam. The diameter of the smart plasma antenna is approximately one wavelength. When one of the plasma tubes has the plasma extinguished, it creates an aperture for the antenna beam. This is an open plasma window. The other plasma tubes are on with the plasma not extinguished. These plasma tubes with closed plasma windows protect the inside antenna from EMI. EMI is reflected from the closed plasma windows of the smart plasma antenna if the plasma density is high enough so that the plasma frequency is greater than the frequencies of the external EMI. The plasma frequency is proportional to the square root of the unbound electrons and is a measure of the amount of ionization of the plasma. If the inside antenna is a plasma antenna then not only is the beamwidth reconfigurable but the bandwidth is reconfigurable with a reconfigurable center line frequency. The reconfigurable bandwidth is equal to the difference in plasma frequencies from the inside plasma antenna and the plasma frequency of the outside cylindrical ring of plasma tubes. Thus by reconfiguring the relative plasma densities of the inside plasma antenna and the outside ring of plasma tubes, the bandwidth and centerline frequencies get reconfigured. This is useful in an RFID reading when some tags need to be read and others ignored through reconfigurable frequency filtering.
Several papers [5]-[7] have been published on plasma antennas and plasma frequency selective surfaces.

I. INTRODUCTION

The steerable smart plasma antenna comprises has a switchable plasma shield of variably plasma elements for controllably opening a transmission window at selected radial angles positioned at an effective distance to intersect at least the transmission radials for the antenna. Preferably, the smart plasma antenna has am omnidirectional in the center and the plasma shield is concentric around the antenna to intersect all transmission radials for the antenna. The plasma shield may also include switchable plasma elements for controlling an elevation angle of the transmission lobe passing through the window, so that the antenna is steerable on two axes.

The electromagnetic shield is formed by a cylindrical annular ring of switched variable plasma elements. In one design, the shield is a ring of plasma tubes extending parallel with the omnidirectional antenna. When the variable plasma elements are non-conducting or at low density in the case of plasma, so that the plasma frequency is lower than the incident transceived frequencies, or if the plasma elements are off and form a transmission window. The omnidirectional antenna can be a conventional metal dipole or other configuration antenna, a plasma antenna or an optical wavelength transmitter. Plasma antennas include nested plasma antennas and even stacked plasma arrays of the same type used to form the shield.

The transmission window is formed by either turning off power to the appropriate electromagnetic shield elements, or otherwise making the desired shield elements transparent to the transmitting antenna, such as by reducing plasma density below the threshhold needed to block transmission of an incident signal frequency. The shield elements are preferably rapidly switchable, so that the radial transmission direction of the antenna can be changed within microseconds, or faster by Perot-Etalon effects. The shield elements are selected for use with antennas broadcasting on a broad range of frequencies.

An alternate design of the shield utilizes a cylindrical array of switchable variable plasma elements to provide more selective control over where openings in the shield are formed. The cylindrical annular shield with the array surrounds an antenna. The elements forming the array are arranged in multiple rows and columns on a substrate. The substrate can be a planar sheet rolled into a cylinder shape. The variable plasma elements can be either switchable regions surrounding air or other dielectrics in fixed gaps or slots, so that the effective size of the fixed slots can be changed rapidly, or the elements can be formed as linear conductors, rectangles, stars, crosses or other geometric shapes of plasma tubes, photonic bandgap crystals or solid state semiconductors on the substrate. The substrate is preferably a dielectric, but may also be made from a conductive metal.

A more complex shield for the antenna has one or more stacked layers, with each layer being a switchable array of variable plasma elements. The layers are spaced within one wavelength of adjacent layers to ensure proper function. Each switchable array in the stack can be a filter, a polarizer or a phase shifter, a deflector, or a propagating antenna. The layers are combined to produce a particular effect, such as producing a steerable antenna transmitting only polarized signals in specific frequency bands.

Layers of annular rings, for example, can be stacked at distances corresponding to wavenumber times distance from the central antenna which correspond to transmission peaks for particular frequencies. By stacking several frequency-selective layers, a multi-frequency antenna is produced which is controllable to selectively transmit and/or receive each frequency along a particular radial of the smart plasma antenna.

In a further design of the smart plasma antenna, the scanner can be used to track a particular RFID ID tag when one or both are moving, without physical re-orientation of the smart plasma antenna scanner. A central unit can be stationary or mobile and has a scanner with one of the two antenna configurations described which is controllable to scan along a specified radial from the scanner. The central unit includes circuits for determining when a connection is made between the scanner and RFID ID tag and maintaining the connection while they move relative to each other. Once a connection is made, the electromagnetic plasma shield of the unit steerable plasma smart antenna is activated to produce only a transmission window and radiation lobe along the radial axis needed to maintain the connection with the central unit. The steerable smart plasma antenna shield on the central and each connected unit is adjusted to compensate for their relative movement while maintaining the connections.

RFID ID tags made of metal which are either passive or actively transmit can be used with the scanner of the invention. An RFID ID tag having a variable plasma element forming the tag antenna is another possibility.

The RFID ID tag with variable conductive element antenna can be an active transmitting or a passive transmitting antenna. Further, the RFID ID tag can have an active variable conductive element or a passive variable conductive element. That is, the antenna is a plasma element which is either connected to an active transmitter, or does not transmit any information and is only sensed by electromagnetic interference. And, the plasma element can be normally powered and active and capable of being sensed by a scanner, or inactive and thus, electromagnetically invisible. The plasma antenna can be normally inactive, but weakly or partially ionized and made active by exciting the plasma element to an active energy state is provided as well.

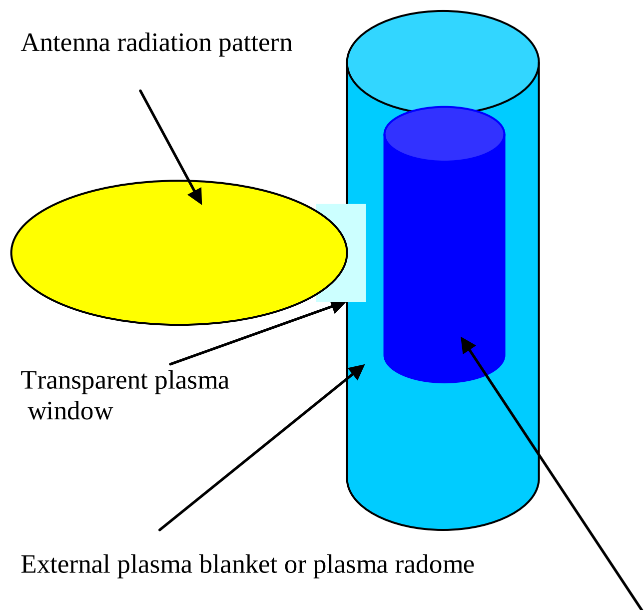
The inactive plasma element is excitable to an active state by an incident received signal. The plasma is energized and permits the RFID ID tag to generate a detectable return signal with date or interference in response to the incident signal. The incident signal may be a scanning signal or other energizing signal. The plasma in the plasma element may be maintained in a weakly or weakly partially ionized state by a power source, such as a battery, laser, voltage source, a radiation source or radioactive source in a known manner, so that the plasma is more easily fully energized by the incident signal.

II. THE SMART PLASMA ANTENNA RFID READER DESIGNS

The concept of creating antenna array characteristics with or without multiple elements is to surround a plasma antenna by a plasma blanket in which the plasma density can be varied. In regions where the plasma frequency is much less than the antenna frequency, the antenna radiation passes through as if a window exists in the plasma blanket. In regions where the plasma frequency is high the plasma behaves like a perfect reflector with a reactive skin depth. Hence by opening and closing a sequence of these plasma windows we create this design electronically steer or direct the antenna beam into any and all directions. This antenna design has the inherent characteristics of smartness. With the correct DSP with feedback and controls This design converts this plasma antenna design into a smart antenna. The advantages of the plasma blanket windowing design are:

1. Beam steering of one omnidirection antenna with the plasma physics of plasma windowing.
2. A reconfiguable directivity and beamwidth
3. The beamwidth can vary from an omnidirectional radiation pattern with all the plasma windows open to a directional radiation pattern with less than all the plasma windows open.

Below is a schematic of a smart plasma antenna RFID reader.



Internal metal or plasma antenna such as an omnidirectional biconical antenna.

Figure 1. Smart Plasma Antenna RFID Reader Schematic

This deign can also replace all the metal antenna elements in a conventional adaptive array with plasma antenna elements. The advantage of the plasma antenna elements is that any combination of them can be turned on or off. Mutual interference among the antenna elements is greatly reduced because the plasma antennas can be created or extinguished on demand. This design can also obtain further resolution and flexibility with even greater degrees of freedoms by replacing the metal antenna elements in a conventional array by the plasma windowing antennas.

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Below is a schematic of a two beam smart plasma antenna RFID reader.

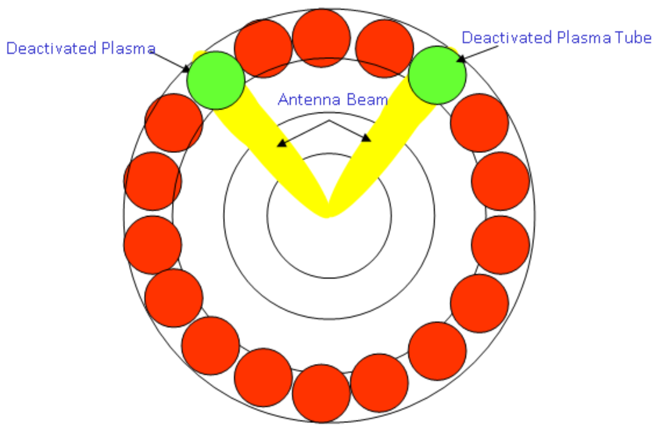

Figure 2. Schematic of a two beam smart plasma antenna RFID reader.

Below is a schematic of a three antenna beam smart plasma antenna RFID reader.

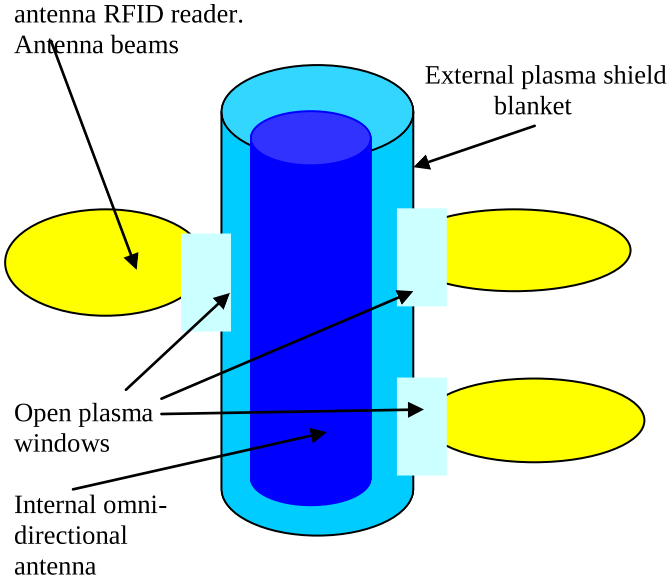

Figure 3. Schematic of a three antenna beam smart plasma antenna RFID reader.

III. SMART PLASMA RFID PROTOTYPES

A prototype smart RFID reader plasma antenna based on the plasma windowing of has been developed. The object is to have an antenna observe a designated transmitter, while disregarding unwanted signals coming in from other azimuth angles. In this way, both unwanted background noise and multi-path reception clutter are reduced. The unit operates at about 2.5 GHz. A ring of plasma tubes operating beyond microwave cut-off surrounds a metal transmitting antenna. A computer de-energizes a plasma tube, causing a lobe of microwave radiation to be emitted. Sequentially de-energizing the plasma tubes causes the radiation lobe on to scan in azimuth. When a receiving antenna is detected, the computer ceases scanning, and locks onto the receiving antenna. When the receiving antenna is disconnected, the computer recommences scanning, looking for another receiving antenna. individual tubes are de-energized in sequence by a computer, and custom designed The signal is received on a simple diode detector, and is fed into the computer. When the received signal exceeds a designated, The plasma tubes are common fluorescent lamps, operating in the cold-cathode mode and wired in series to a high-voltage DC supply. To de-energize a specific tube, it is short-circuited by a high voltage Jennings switch. The individual tubes are de-energized in sequence by a computer, custom designed by Impeccable Instruments. The signal is received on a simple diode detector, and is fed into the computer. When the received signal exceeds a designated, adjustable threshold, the computer ceases scanning, and holds this window open. If the received signal subsequently drops below this threshold, the computer recommences the scanning process. The present scanning rate can be adjusted from milliseconds to about a second per tube. The basic idea is to have an intelligent antenna look in space for a transmitter or receiver, lock on to the receiver or transmitter direction when found to increase signal to noise ratio, disconnect from the receiver or transmitter direction when the signal is lost and resume scanning. Please see the smart plasma antenna video on YouTube.

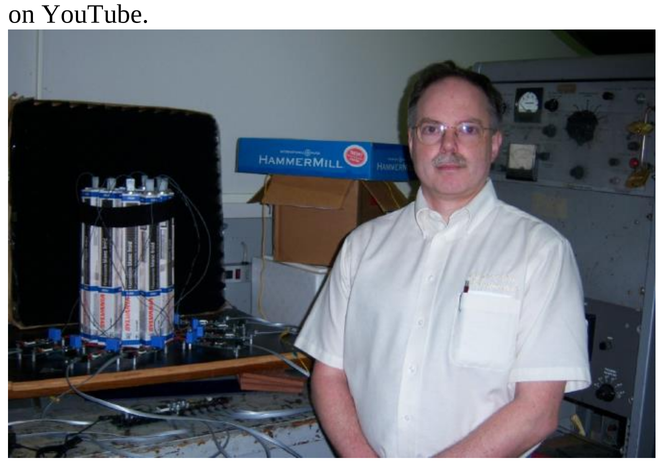

Figure 4. Smart plasma antenna RFID reader with engineer

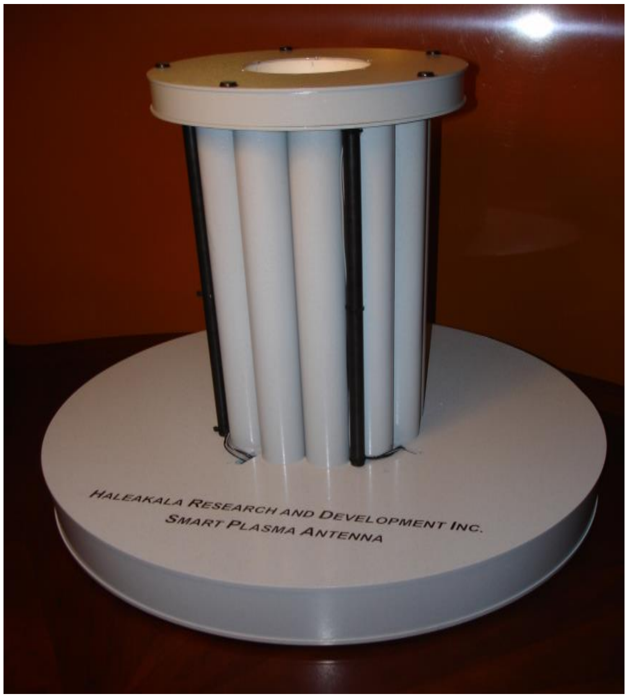

Figure 5.Ruggedized smart plasma antenna RFID reader with engineer prototype.

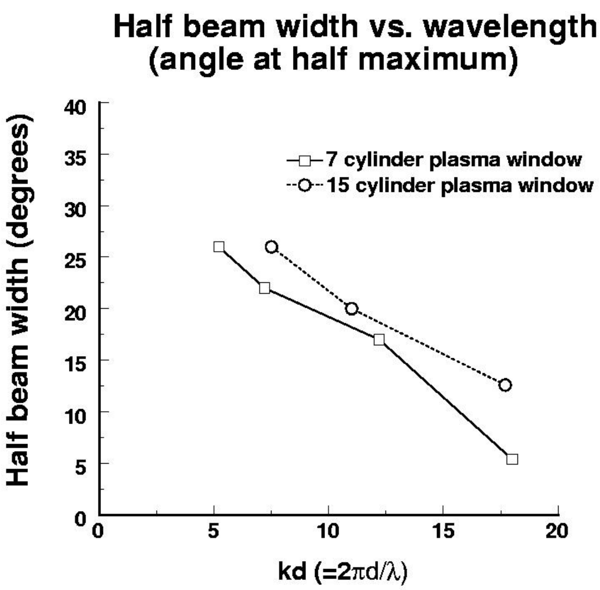

Figure 6. . Half power beam-width versus wavelength for a 8 cylinder smart plasma antenna RFID reader with one window and a 16 cylinder smart plasma antenna RFID reader with one plasma window

Figure 6. . Half power beam-width versus wavelength for a 8 cylinder smart plasma antenna RFID reader with one window and a 16 cylinder smart plasma antenna RFID reader with one plasma window.

IV. CONCLUSIONS

The adaptive directionality of the smart plasma antennas provides a plethora of advantages. The directivity of each antenna beam minimizes the power levels broadcast which might interfere with adjacent users. In this sense, it provides a form of SDMA. The directivity of the antenna also reduces the power levels that could be detected by unfriendly agents. The adaptive nature of the smart plasma antenna allows the beam to follow the user with a minimum of computation required, as well as to alter the beamwidth depending if the user is in an area of high user density or requiring greater stealth, where the beam can be made very narrow, or if the user is relatively isolated moving at a great speed, where the beam can be made wider.

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