PLASMA ANTENNAS: DYNAMICALLY CONFIGURABLE ANTENNAS FOR COMMUNICATIONS

Gerard Borg, David Miljak*, Jeffrey Harris and Noel Martin†

Plasma Research Laboratory
Research School of Physical Sciences
Australian National University
Canberra ACT 0200
Australia

**Wills Plasma Physics Department*
School of Physics, University of Sydney
Sydney, New South Wales, 2006
Australia

† *Defence Science and Technology Organisation*
P.O. Box 1500, Salisbury, South Australia , 5108
Australia

In recent years, the rapid growth in both communications and radar systems has led to a concomitant growth in the possible applications and requirements of antennas. These new requirements include compactness and conformality, rapid reconfigurability for directionality and frequency agility. For military applications, antennas should also allow low absolute or out-of-band radar cross-section and facilitate low probability of intercept communications. Investigations have recently begun worldwide on the use of ionised gases or plasmas as the conducting medium in antennas that could satisfy these requirements. Such plasma antennas may even offer a viable alternative to metal in existing applications when overall technical requirements are considered. A recent patent for ground penetrating radar claims the invention of a plasma antenna for the transmission of pulses shorter than 100 ns in which it is claimed that current ringing is avoided and signal processing simplified compared with a metal antenna. A recent US ONR tender has been issued for the design and construction of a compact and rapidly reconfigurable antenna for dynamic signal reception over the frequency range 1 – 45 GHz based on plasma antennas.

Recent basic physics experiments at ANU have demonstrated that plasma antennas can attain adequate efficiency, predictable radiation patterns and low base-band noise for HF and VHF communications. In this paper we describe the theory of the low frequency plasma antenna and present a few experimental results.

For frequencies below the plasma frequency, plasma columns support electromagnetic guided waves as a result of axial propagation of the m = 0 surface wave. This wave propagates at the speed of light at low frequencies. Figure 1. shows the antenna radiation resistance for a plasma antenna monopole supporting surface waves along the plasma column at 30 MHz. On the vertical axis is the ratio of frequency to collision frequency and along the horizontal axis is the ratio of frequency to plasma frequency. These results are obtained by computing the allowed values of k from the dispersion relation of the surface wave and employing them to calculate the antenna radiation resistance from a text book formula for a monopole. When the collision frequency is low with respect to the wave frequency and the wave frequency much lower than the plasma frequency, the wave undergoes ¼ wave resonance as would be expected for L/2. = 2.5 m. Here the antenna radiation resistance is about 36 Ohm as expected. Figure 1 shows that a large range of plasma parameters exists for which the plasma antenna operates like a copper antenna.

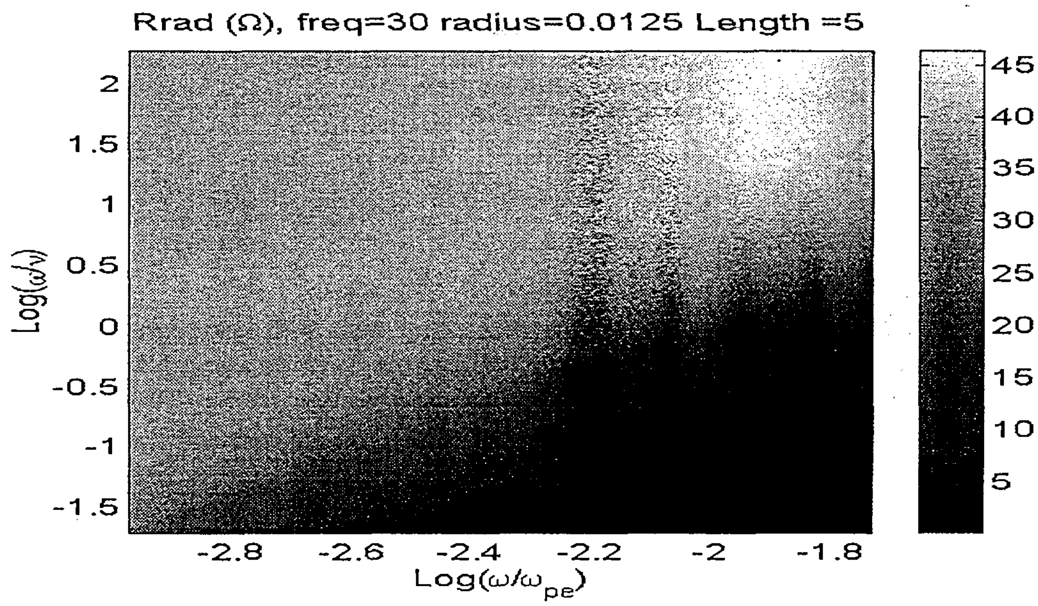


Figure 1.

Figure 2 shows a typical experimental arrangement for the measurements. A copper cylindrical sleeve wrapped around the base of an electrodeless tube containing a low pressure gas (typically argon at ~ 1 Torr) couples to the m=0 surface wave on the column. Usually a fluorescent lamp was used for this purpose but without the usual mains circuitry. For a tube of length L = 2430mm and diameter D = 38mm illumination was possible with less than 200W of r.f. power, and less than 50W for a tube with L = 614mm, D = 38mm. The figure also shows some diagnostics.

Pulsed operation has also been demonstrated at 10% duty-cycle (100 μs on and 1 ms off) which allowed similar density plasmas to be produced at one tenth the r.m.s. power consumption. This feature arises due to the long (~ 5 msecs) plasma density decay time versus the relatively short electron energy confinement time for plasma tubes at modest filling pressures.

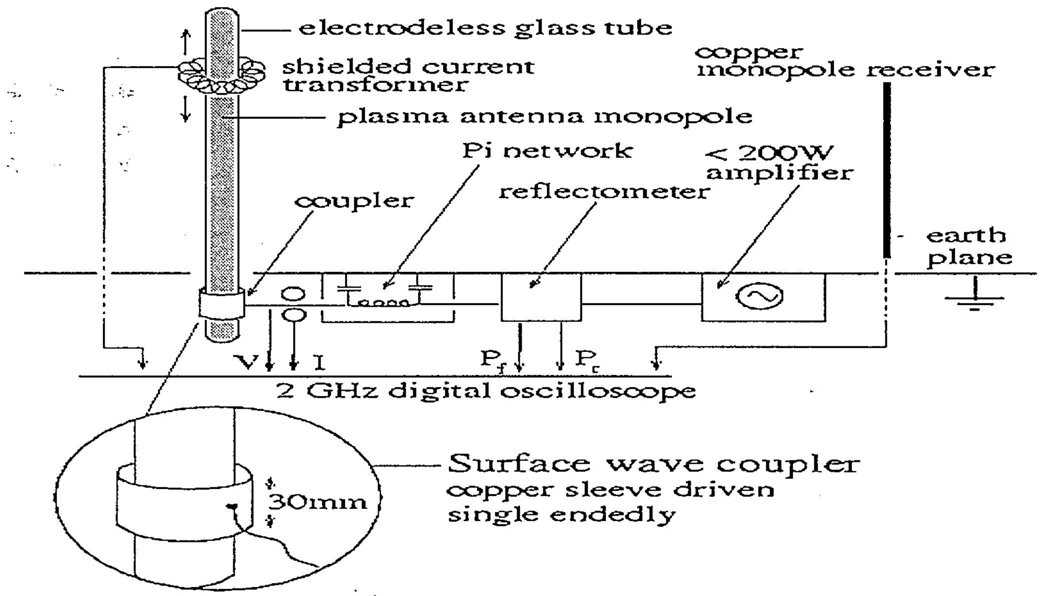
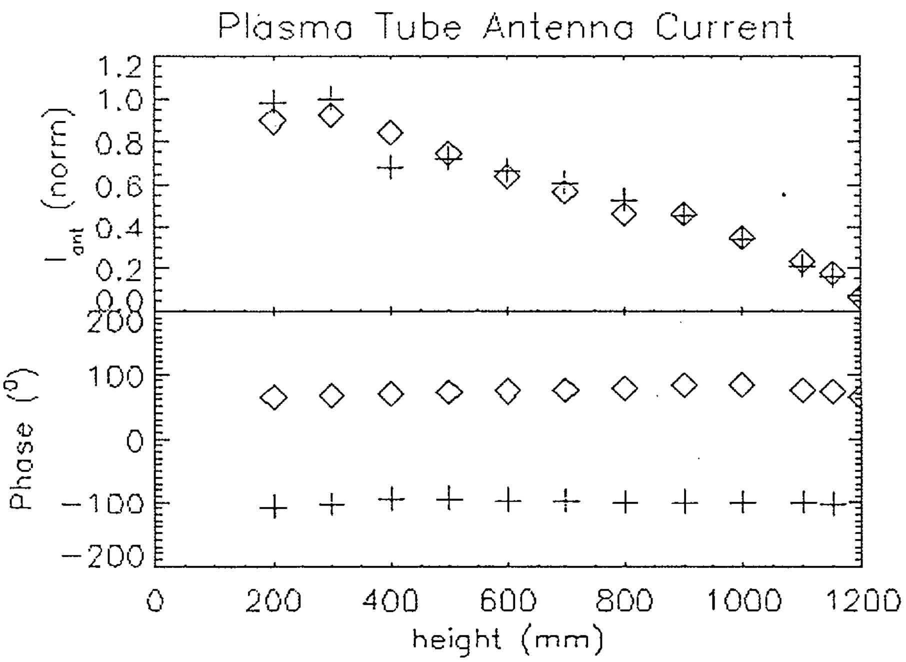


Figure 2.

Figure 3 shows the current distribution along a fluorescent tube with L = 1220mm and D = 25.4mm excited at 30 MHz. The horizontal axis measures distance away from the base of the antenna where the r.f. is coupled by a 30 mm long copper sleeve. The diamonds and '+' symbols simply refer to different orientations of the current transformer. The antenna is less than one quarter-wavelength long so that the only current node is at the end of the antenna (z = 1200 mm). The phase is flat along the antenna as would be



expected for a standing wave. This however was not the case if the power were lowered, causing the density to drop. For low enough densities, the antenna current is attenuated and propagates along the tube.

Radiation patterns were recorded on a test range. Two half-wave dipole antennas, one of copper and the other of plasma, were driven at 141 MHz. The resultant measured equatorial E-field is shown in Figure 4 for which the antennas were aligned along the horizontal axis. The plasma antenna is shown at the top and the copper antenna at the bottom. These show the characteristic "figure 8" radiation patterns expected for a half-wave plasma dipole antenna. The radial distance from the origin in the figures is proportional to the equatorial electric field strength in each case. The scales are the same and indicate a 25 - 50% efficiency for the plasma antenna.

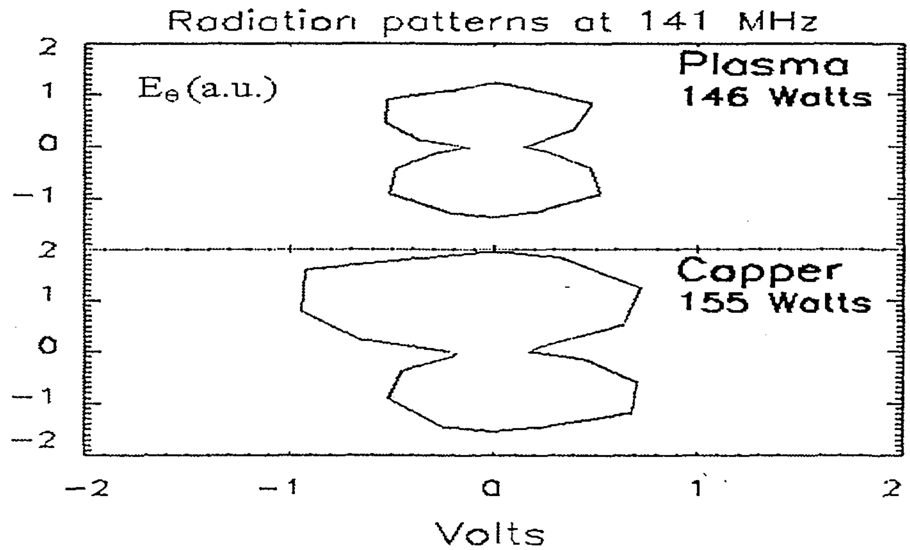


Figure 4.

In summary, we have demonstrated that HF and VHF radio transmission from plasma antenna dipole elements is an efficient process with about half the power radiated for a tuned quarter-wave antenna. The powers required to drive the plasma may be as low as a few tens of Watts average and are comparable to powers used in typical mobile communications. In other experiments, we have considered communication transmission achievable by an antenna whose plasma drive is also the signal carrier. Reception on the other hand must be achieved by two frequency operation where one frequency is used to drive the plasma and the other is used for signal reception. Two frequency operation has been shown to be feasible and is a largely technical issue.

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