I-338 ① Ha. 132

NOVEMBER 1981

PPPL-1853
UC-20A,F

MASTER

# PLASMA SWEEPER TO CONTROL LOWER HYBRID WAVE COUPLING

BY

R.W. MOTLEY AND J. GLANZ

## PLASMA PHYSICS LABORATORY

## PRINCETON UNIVERSITY
## PRINCETON, NEW JERSEY

This work was supported by the U.S. Department of Energy Contract No. DE-AC02-76-CHO 3073. 

Plasma Sweeper to Control Lower Hybrid Wave Coupling*

R. W. Motley and J. Glanz

Plasma Physics Laboratory, Princeton University
Princeton, New Jersey 08544

## ABSTRACT

Experimental tests of an $\bar{E}\times\bar{B}$ plasma sweeper, designed to control the plasma density near the mouth of a phased waveguide array, are described.

## INTRODUCTION

The phased waveguide array is the most promising antenna for launching high frequency waves to heat and drive current in toroidal plasmas.[1,2] Good RF power coupling requires that the mouth of the array be placed within a few millimeters of an overdense plasma. Optimum coupling occurs if the density of the edge plasma is $n_e \approx n_c n_\parallel^2$, where $n_c = m_e \omega^2/4\pi e^2$ is the critical density and $n_\parallel = ck_\parallel/\omega$ is the (parallel) refractive index.[3] Variation of the density from the optimum by an order of magnitude can increase the power reflection by a factor of 2-3 and lead to waveguide arcing.

It is difficult to predict how the plasma near the edge of a torus will change in response to a high power (>1 kW/cm$^2$) pulse of rf power. In general there will be some local power absorption, so that the density will tend to rise as a result of increased ionization. Other effects, such as ponderomotive wave pressure, may reduce the density, but only if the rf power density is high and the background pressure is low.[4] Measurements on the PLT device show a power-dependent rise in waveguide reflection above 100-150 kW, which may be caused by the formation of a high density plasma layer near the mouth of the guide. If this plasma originates outside the waveguide, it may be possible to reduce its concentration by means of sweeping electrodes. If this reduction is significant, the guide reflectivity would drop, permitting a larger fraction of power to pass into the plasma and reducing the probability of arcing.

In this paper we describe tests of an $\bar{E}\times\bar{B}$ plasma sweeper, designed to permit one to adjust the plasma density in the thin (<1 cm) coupling layer near the waveguide mouth. The sweeper electrodes, shown in Fig. 1, are positioned at the edge of the cylindrical test plasma (2 m long by 10 cm diam.), 6.7 cm displaced from each side of a 2-element array. The edges of the electrodes extend 2-3 mm beyond the waveguide. Potentials up to 40 V were applied to the electrodes after an rf discharge in the main column, ($B \sim 10$ kG, $n_e \lesssim 10^{12}$ cm$^{-3}$).[5] The potential gives rise to a (primarily) horizontal electric field $E = -V_o/\delta$ just outside the electrodes. In response to the crossed electric and magnetic fields the plasma should drift vertically at a speed

$$v_D = cE/B \ . \qquad (1)$$

Plasma in contact with the center of the waveguide is replaced by low density plasma near the bottom of the guide in a time $\tau \sim H/v_D$, where H is the height of the guides. The density of the surface plasma will then drop if $\tau$ is shorter than the time for replacing the plasma by ionization or by diffusion from the dense plasma core. In our experiment $\tau \sim 60$ μsec, if $v_D$ is ~1/2 the sound speed ($C_s \sim 2 \times 10^5$ cm/sec in argon).

Lower hybrid waves were excited in the plasma column using the 2-element array of Fig. 1, driven by a 2.45 GHz magnetron.[6] The reflected power, monitored by directional couplers, is shown in Fig. 2. In the absence of any potential on the side electrodes, the waveguide reflectivity was < 10% ($180^\circ$ excitation) or ~40% ($0^\circ$) and changed little with time. If a voltage pulse exceeding ~ +10 V was applied to the electrodes, however, the reflection varied in time. With a potential of 23 V the reflectivity (at $180^\circ$) began to rise after ~50 μsec, reaching a maximum of 50% if $V_o > 20$ V. There is a corresponding drop in reflection to ~17% at $0^\circ$ excitation. These changes imply a decrease in the density near the waveguide (initially $\sim 5 \times 10^{11}$ $cm^{-3}$) by an order of magnitude.

To test this inference we scanned the plasma vertically with a Langmuir probe within a few mm of the waveguide. As shown in Fig. 3 this surface plasma moved vertically at a speed of $\sim 10^5$ cm/sec. The density near the waveguide midplane dropped by a factor of ~10 within 100 μsec after application of the voltage and was responsible for the change in the waveguide reflectivity. Little change was observed in the reflection or the plasma position if the applied potential was negative.

A drift speed of this magnitude implies an electric field ~10 V/cm. Horizontal measurements of the floating potential, given in Fig. 4, show that such a field exists and falls off exponentially over a distance of 1/2 to 1 cm in front of the electrodes (this for a positive applied potential). We find empirically that

$$\delta = \frac{50\sqrt{pA}}{B} \text{ cm} , \qquad (2)$$

where p is the gas pressure ($0.05 < p < 1$ m torr) in torr, B is the magnetic field ($3 < B < 15$ kG) in kilogauss, and A is the atomic mass of the ion. The drift speed $v_D$, at constant pressure and applied potential, is independent of the magnetic field, consistent with Eq. (1) and (2).

The theoretical explanation of Eq. (2) must center on balancing current flow along the field lines from the conducting end plates with cross-field current flow. The most likely mechanism for cross-field flow is collisional friction between the ions and background atoms, as previously concluded by Okabayashi and Yoshikawa[7] and by Strait.[8] A quantitative theory of the sweeper is in preparation.

Our tests demonstrate only an enhancement of reflectivity for the most useful phase setting ($180^o$), because the maximum density possible in the test plasma ($2 \times 10^{12}$ $cm^{-3}$) is comparable to the optimum coupling density ($10^{12}$ $cm^{-3}$). In hot toroidal plasmas, however, edge densities can greatly exceed this optimum,[9] so that the addition of a sweeper may improve the performance of the phased array.

Acknowledgments

We acknowledge with pleasure the technical assistance of J. Frangipani.

*Work supported by the U.S. Department of Energy Contract No. DE-AC02-76-CHO3073.

## REFERENCES

[1]P. Lallia, in Proc. of 2nd Topical Conf. on RF Plasma Heating (Texas Tech. University, Lubbock, Texas, 1974) paper C3.

[2]M. Brambilla, Nucl. Fusion 16, 47 (1976).

[3]J. Stevens, private communication.

[4]R. W. Motley, W. M. Hooke, and C. R. Gwinn, Phys. Letters 77A, 451 (1980).

[5]R. W. Motley, S. Bernabei, W. M. Hooke, and D. L. Jassby, J. Appl. Phys. 46, 3286 (1975).

[6]R. W. Motley, Phys. Fluids 23, 2050 (1980).

[7]M. Okabayashi and S. Yoshikawa, Phys. Rev. Lett. 29, 1725 (1972).

[8]E. J. Strait, D. W. Kerst, and J. C. Sprott, Phys. Fluids 21, 2342 (1978).

[9]J. J. Schuss, S. Fairfax, B. Kusse, R. R. Parker, M. Porkolab, D. Quinn, I. Hutchinson, E. S. Marmar, D. Overskei, D. Pappas, L. S. Scaturra, and S. Wolfe, Phys. Rev. Lett. 43, 274 (1979).

## FIGURE CAPTIONS

Fig. 1. Schematic of the sweeper. Diameter of plasma column is 10 cm, and the height of sweeper electrodes 6.5 cm; each electrode is separated from the nearest guide by 6.7 cm.

Fig. 2. RF reflection in time, with the waveguides in (a) or out (b) of phase B = 12 kG. The rise time of the voltage pulse, applied at t = 0, was 40 μsec.

Fig. 3. Vertical scans of plasma density (ion current to a Langmuir probe) 3.5 mm from waveguide. B = 6.0 kG, $p = 1.2 \times 10^{-4}$ Torr argon. $V_o = 13$ V.

Fig. 4. Typical floating potential profiles. Measurements are along the midplane, as shown. Here, B = 12.0 kG, pressure = $2.8 \times 10^{-4}$ Torr.

# 81X1138

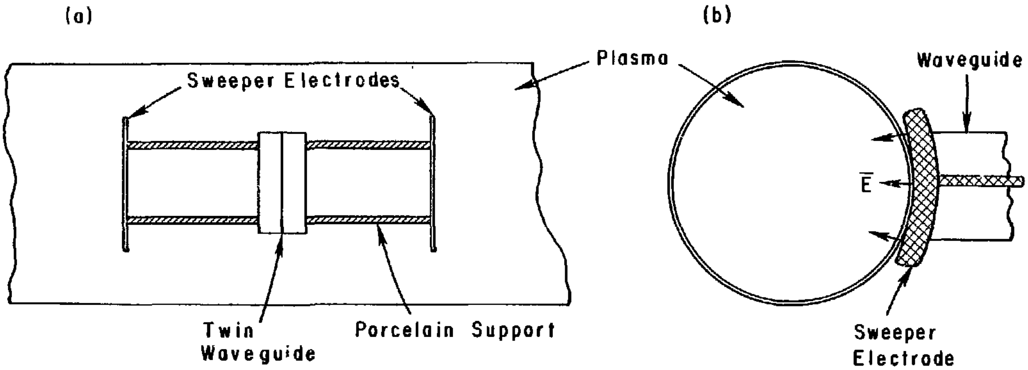
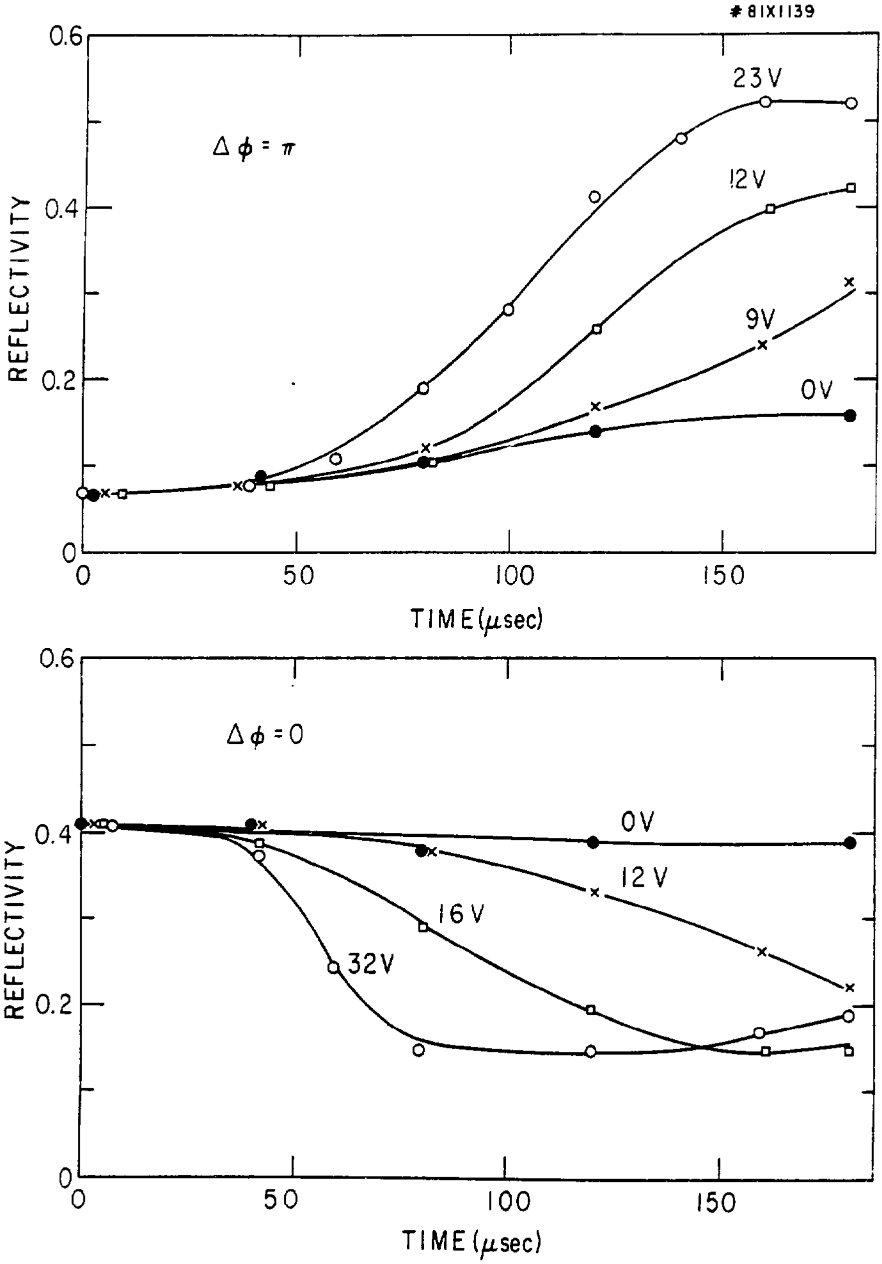



Fig. 1



# 81X1139
0.6
0.4
0.2
0
REFLECTIVITY
Δ φ = π
23 V
12 V
9 V
0 V
0
50
100
150
TIME (μsec)
0.6
0.4
0.2
0
REFLECTIVITY
Δ φ = 0
0 V
12 V
16 V
32 V
0
50
100
150
TIME (μsec)


Fig. 2

# 81X1140

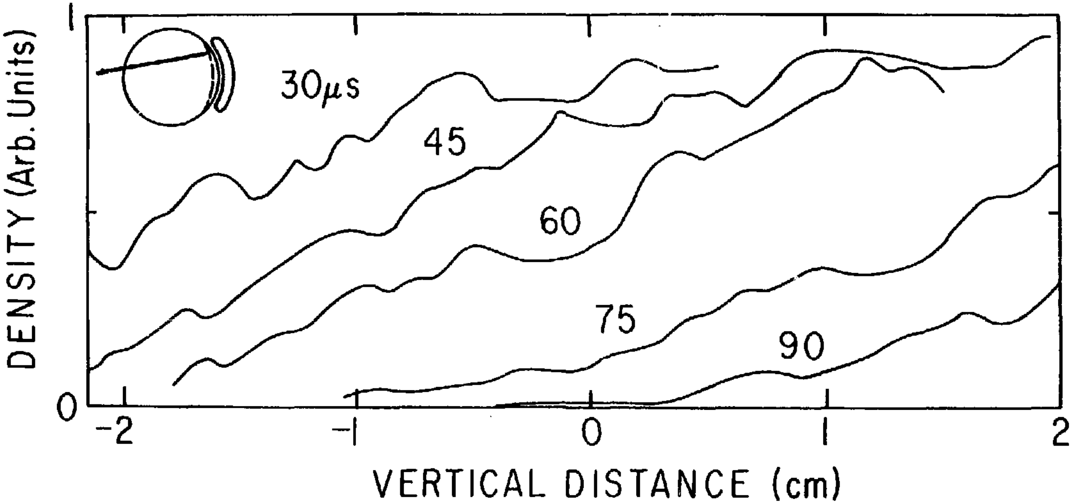
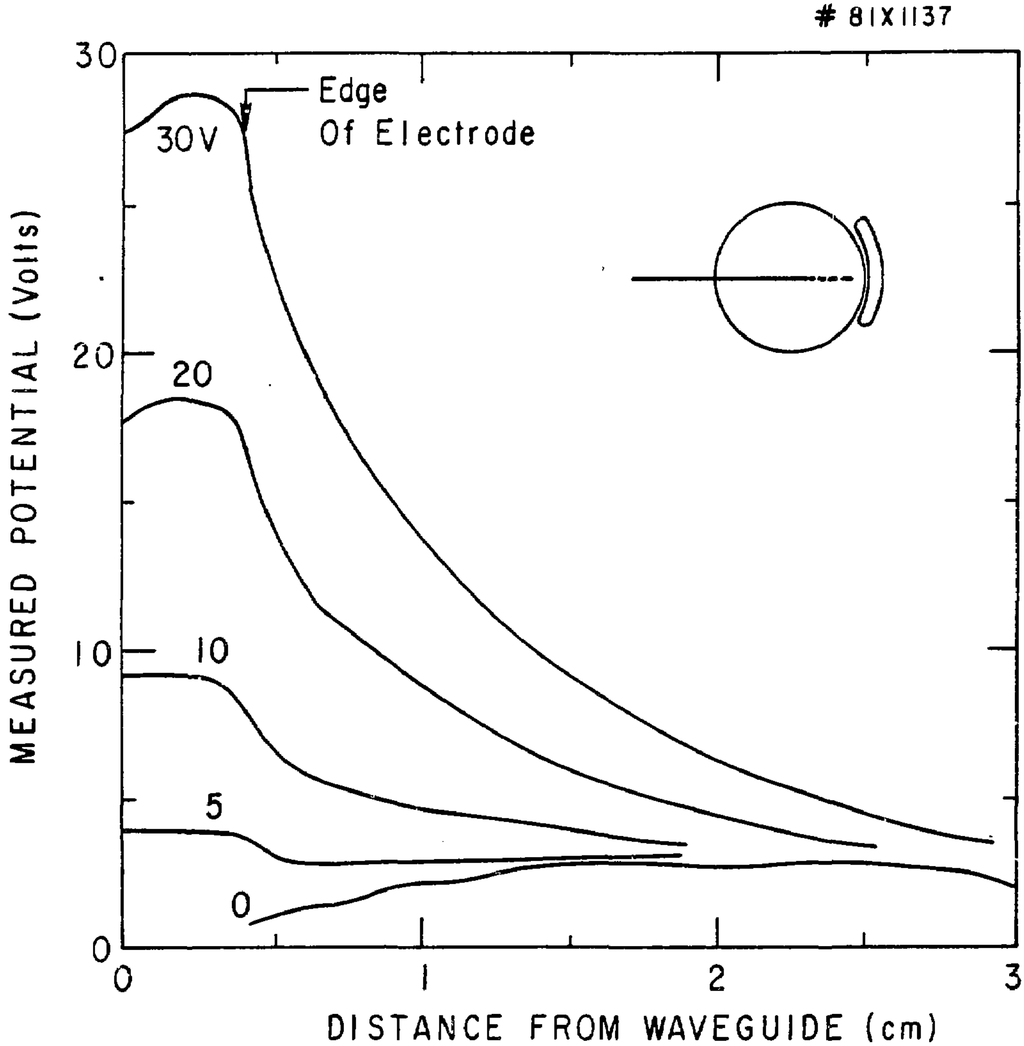



Fig. 3

-6-



# 81X1137
Edge
Of Electrode
30V
20
10
5
0
MEASURED POTENTIAL (Volts)
DISTANCE FROM WAVEGUIDE (cm)
0
1
2
3
10
20
30


Fig. 4