The Introduction of a High Frequency Non-Perturbative Plasma Microprobe

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(Dated: August 24, 2004)

A high frequency plasma microprobe was built to collect data form the plasma current sheet in the Large Plasma Device (LAPD). The size of the microprobe was fundamental in collecting data so as to not perturb the plasma. Electron phase space holes were the target of study, yet hey were not detected. Lower Hybrid waves were observed in a current sheet embedded in magnetized plasma.

INTRODUCTION

Collecting data from plasma is significant to understanding exactly what it is and its behavior. Thus far, ways of collecting data have been done using Langmuir probes and Laser Induced Fluorescence (LIF). Unfortunately these methods cannot give an accurate indication of the activity occurring in the plasma; they rather give an indication of the activity occurring in perturbed plasma. In this paper we introduce a non-perturbative high frequency microprobe that collects data in a current sheet of plasma without being effected by Debye shielding.

DEBYE SHIELDING

Plasma is a quasinuetral gas of charged and neutral particles, which exhibits collective behavior. One critical aspect of this collective behavior is the plasmas ability to shield out electric fields. When a perturbing charge is applied to a plasma it generates an electric field, in order to shield this electric potential, the charges in the plasma redistribute themselves. However, if the electric field present in the plasma is shorter than the Debye length of the plasma, the plasma will not recognize it and therefore remain unperturbed. The Debye length is given by:

$$\lambda_D = \left(\frac{\varepsilon_0 K T_e}{2 n_0 e^2} \right)^{1/2} \qquad (1)$$

Where λ_D is the distance over which the usual Coulomb 1/r potential drops off exponentially by the shielding from the plasma. Note that the Debye length depends on the density(n_0) and the electron temperature(T_e). As the density increases, λ_D decreases and as the electron temperature increases, λ_D also increases.

Electron temperature is used in the equation because it is more mobile than ions, hence it does most of the shielding. The Debye length of our plasma is 30 microns and so as to not perturb the plasma, a probe smaller in measurement of 30 microns was needed.

PROBE DESIGN

In addition to building a non-perturbative probe, we also wanted a probe that could detect electron phase space holes. Electron phase space holes are regions of depleted electron density. These phenomenon are due to changes in potential and are known to travel at high speeds and therefore, a high frequency probe was needed to detect them. 2.4 GHz amplifiers were connected to each prone in order to measure potential fluctuations in a current sheet of the plasma.

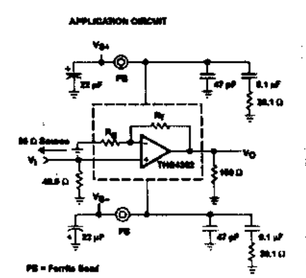

FIG. 1. Amplifier circuit

Each probe consisted of 20-micron wire, which was threaded through ceramic tubing about in width. We coated each tube with silver paint and connected each wire to an amplifier using silver paste. The copper and silver were used because of their conductivity. Figure 2 shows how the amplifiers and probes were arranged on the circuit board.

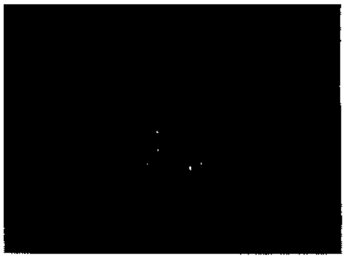

FIG. 2. Final view of the probe

The probes are paired with a 1cm gap between the pairs. The probes are set up this way so as to test for coherency in the waves. The probe setup is then placed in a copper box. The copper box shielded the amplifiers from being directly effected by the current sheet.

FIG.3. Probe in copper box

EXPERIMENTAL SETUP

The probe is placed in a probe shaft, which also contained a copper tube that air was blown through constantly for the duration of the time the probe was in the plasma chamber. Then the probe is placed in the plasma. The type of plasma used in our experiment is helium plasma. Its density was $2*10^2$ ions/cc and consisted of all ions and electrons. The ion temperature and electron temperature were approximately 1Ev and 6eV respectively. The plasma was pulsed and each pulse lasted 8ms. The plasma column had a 60cm diameter and was 18 meters long. The current sheet that we collected data from had a thickness of .5cm, a height of 17cm, and was 18 meters long.

DATA

Using the probe, we collected data as a function of time from a current sheet, about a 1cm wide, in the plasma. We digitized over 15,000 time steps and recorded 30 shots at 21 different positions. Each time step was 200picoseconds long and each change in position was 5mm long. With the data collected, we designed a computer program that produced fast-Fourier transforms with the data. Using the FFT'S we developed frequency spectrums and then determined the coherency of the waves detected.

Fast-Fourier Transforms

A fast-Fourier transform is an efficient algorithm to compute discrete Fourier transform and its inverse. They are used in signal processing to transform a signal from the time domain to the frequency domain. Since our probe collected 30 shots from each position for each probe, we had to average the 30 shots at each position for each probe to get a single FFT for each position.

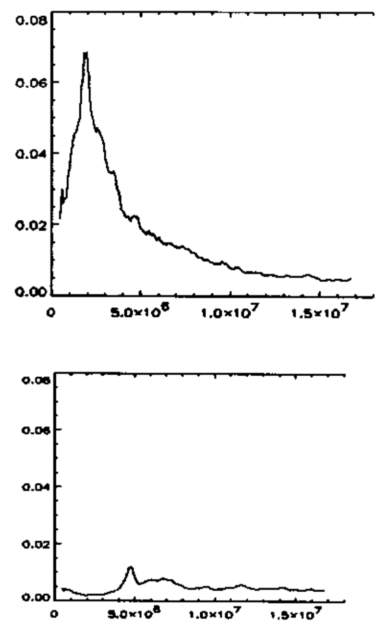

FIG. 3: (a) FFT of probe1 at position 10 (b) FFT of probe1 at position 20

Position 10 corresponds to the probe being directly in the current sheet while 20 is outside of the current sheet.

Frequency Spectrum

Using the fast Fourier transforms we created frequency spectrums for the probes. The frequency shows the frequency of the probe as a function of time.

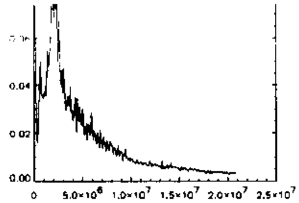

FIG. 4: Frequency spectrum

Coherency

As previously stated, the arrangement of the probe enables us to determine the coherency of the detected waves across different distances. To determine the coherency we use the equation:

$$\gamma^2 = \frac{\left|\langle \varphi_1 \varphi^*_2 \rangle\right|^2}{|\varphi_1|^2 |\varphi_2|^2} \quad (2)$$

Where φ_1 is the Fourier transform of the potential from one probe tip and φ_2 is the Fourier transform of the potential from another probe tip.

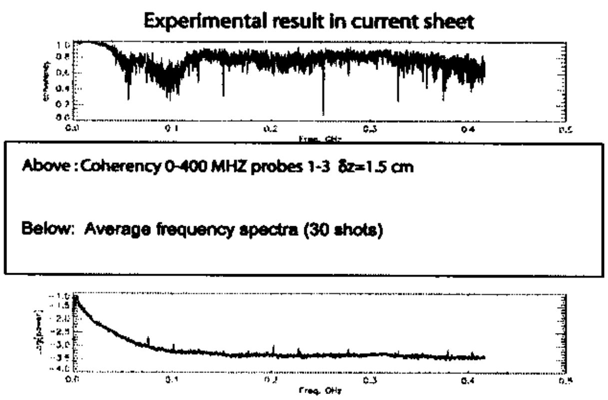

FIG.4: Coherency of probe 1 and 3

There is coherency of probes 1 and 3 at a frequency of approximately 60 MHz and 130MHz. From previous research we know that at these frequencies the waves can be categorized as lower hybrid waves and whistler waves respectively. Since the power is low at 130MHz, we can omit those waves because the signal is weak.

CONCLUSION

Lower hybrid waves were detected using the high frequency non-pertubative probe. The data shows that there was only coherency in the waves at lower frequencies. Although electron phase space holes were not detected, we can consider this experiment a success and a step forward to understanding more about plasma.

ACKNOWLEDGMENTS

I would like to thank Walter Gekelman and Pat Pribyl for their guidance throughout this research project. I would also like to thank Troy Carter, Mio, and Stephanie for their contribution to the completion of the project. In addition I wish to thank the National Science Foundation (NSF) for funding the program and Franciose Queval for presenting me with this opportunity.

[1] F.F. Chen, *Introduction to Plasma Physics* (Plenum Press, New York, 1974)

[2] *Plasma Physics: an Introductory Course*, edited by R. Dendy(Cambridge University Press)