Comparing the performance of plasma impedance probes and Langmuir probes for RF plasma diagnostics

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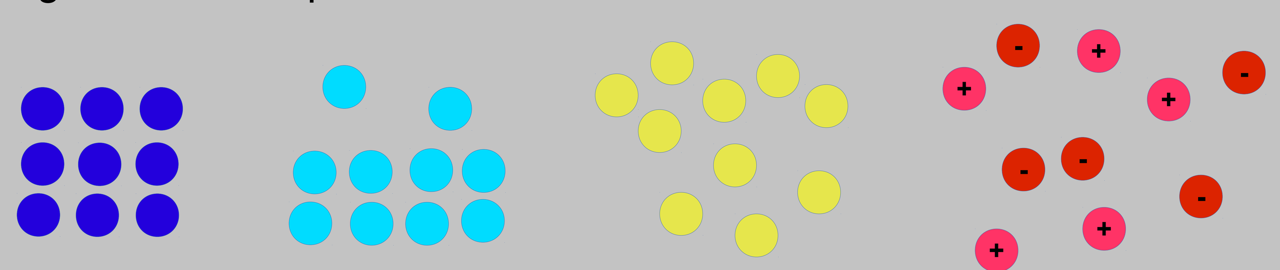
Objective

Plasma is the most abundant form of matter, yet it is not well understood due to the paucity of it on Earth. Because plasma has become an integral part in certain industrial processes and particularly in the field of electric propulsion, developing accurate and robust diagnostic techniques is critical.



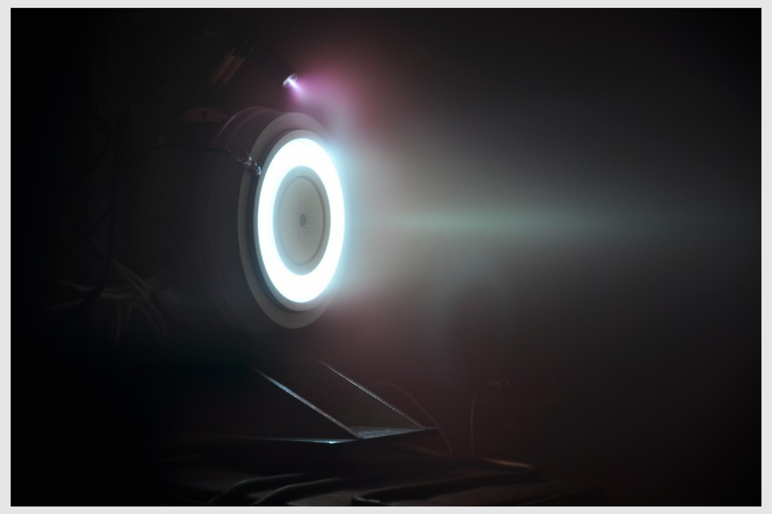
The de facto diagnostic for many plasma parameters is the Langmuir probe. An alternative to this instrument is the plasma impedance probe, or resonance probe. This research focused on the development and operation of a resonance probe. Specifically, the following goal was set forth:

Construct a resonance probe and compare its ability to measure electron density to a Langmuir probe for both discharge and RF plasmas.

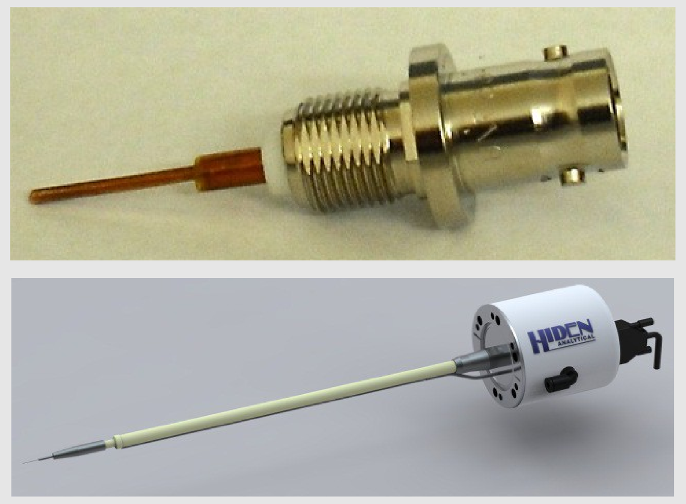
Background

The Langmuir probe is a coaxial electrode device that, immersed in a plasma, experiences a current that is dependent on the potential difference between its electrodes. Langmuir probe techniques have many issues, such as vulnerability to noise. Resonance probing, a less developed technique, can possibly overcome these problems.

Better plasma diagnostic tools can impact industry and the scientific community. More reliable plasma quantification allows for more efficient industrial processes, such as plasma circuit etching. Understanding the state of a plasma can also reveal the efficiency of electric propulsion systems, like Hall Effect Thrusters. More robust instruments also allow for more effective studies of the radiation environment around Earth and other planets.



Georgia Tech High-Power Electric Propulsion Laboratory, T-140 Hall Effect Thruster.



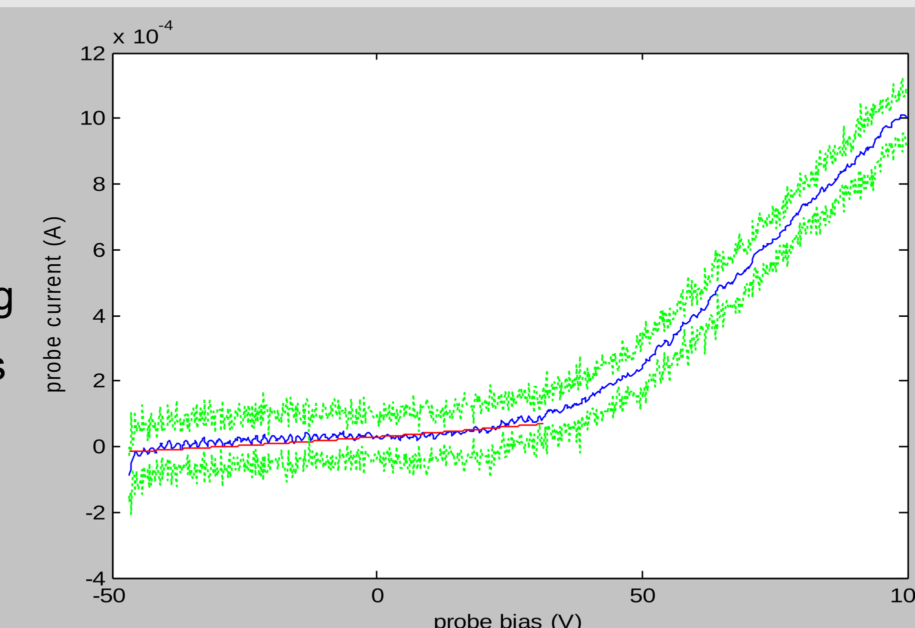
A resonance probe (top) and a Hiden Analytical Langmuir probe (bottom).

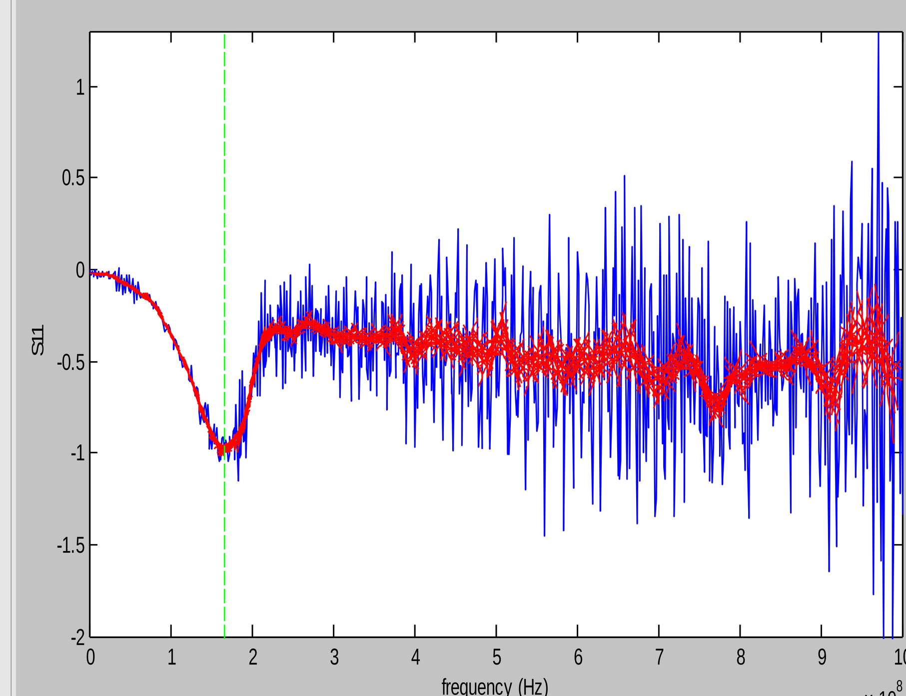
Approach & Analysis

Electron density was measured with a Langmuir probe and resonance probe for a discharge plasma as a means of calibration. These measurements were repeated in an RF plasma for comparison. A Hiden Analytical Langmuir probe and electronics box was used for Langmuir probe measurements. A custom-built resonance probe and an HP8753E network analyzer was used was resonance probe measurements. Experiments were conducted in a 14-ft diameter, 22-ft long diffusion-pumped vacuum chamber. Plasma was produced with a cylindrical helicon thruster, which produces plasma by creating and absorbing low frequency electromagnetic waves via RF heating.

Discharge Case, Langmuir Probe

Langmuir and Mott-Smith's orbital motion limited theory was used to determine electron density. Applying exponential curve fits at high biases and low biases allowed electron temperature and ion saturation current to be determined.



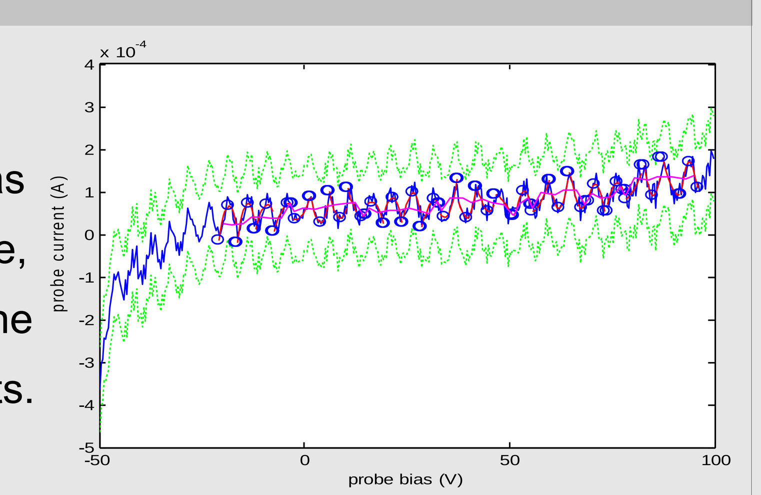


Discharge Case, Resonance Probe

A resonant circuit analogue to was used to determine electron density from plasma frequency. The frequency of minimum scattering parameter corresponded to the upper hybrid frequency.

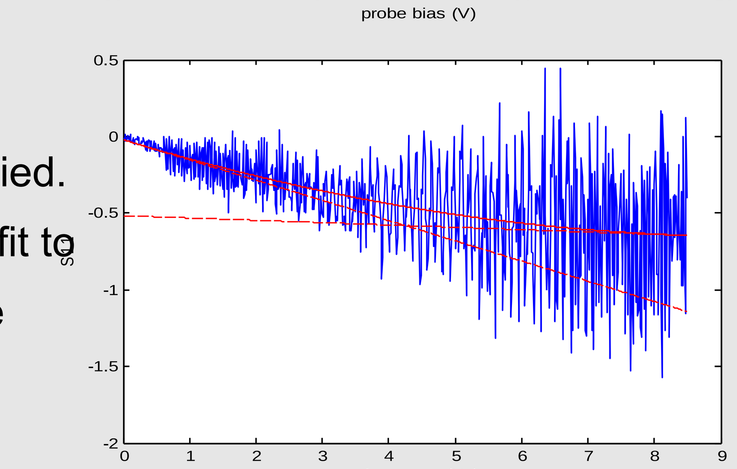
RF Case, Langmuir Probe

The ion limit of orbital motion limited theory was used to determine electron density. In this case, second-order curves were fit to the data and the extrema were used as anchor points.



RF Case, Resonance Probe

The resonant circuit analogue was again applied. To determine plasma frequency, a curve was fit to the relevant data and the end conditions were used to find the "knee" of the curve.

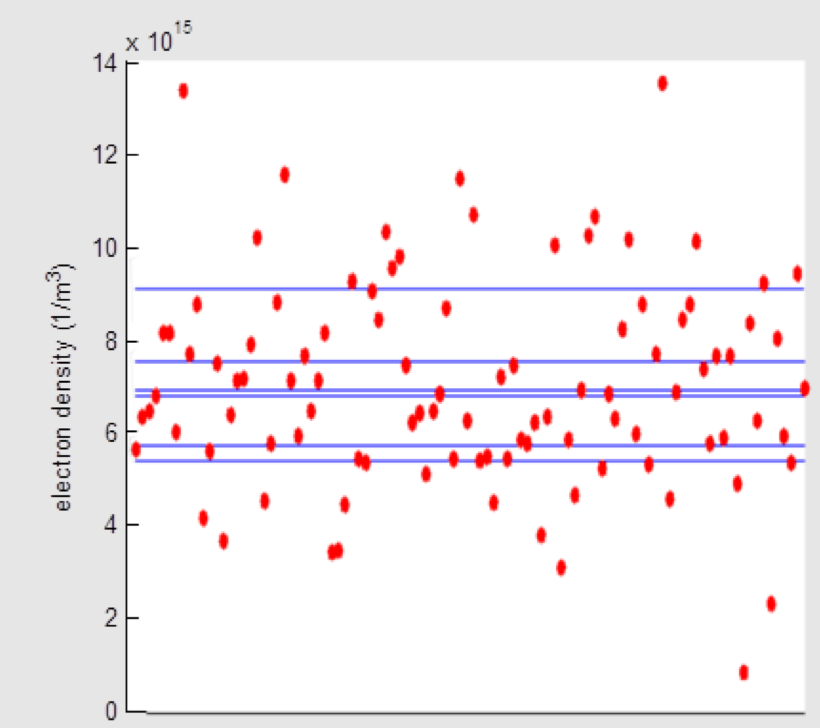


Results

Probe	Discharge Plasma (m^{-3})	RF Plasma (m^{-3})
Langmuir	$(6.92 \pm 2.65) \times 10^{15}$	$(1.66 \pm 0.191) \times 10^{16}$
Resonance	$(1.72 \pm 0.0557) \times 10^{14}$	$\sim 2.07 \times 10^{15}$

Monte Carlo Analysis

Leveraging the large number of current measurements made per Langmuir probe trial, a current distribution was found. Random artificial data sets were products and the variability examined. It was found comparable to that of the experimental values. This suggests that the variability of the Langmuir probe data was inherent to the measurements made by the probe and the reduction method employed.



Conclusions

For the discharge plasma condition, there was a significant difference in electron density from each diagnostic. The low uncertainty of the resonance probe measurements rules out transient plasma effects and so the cause is most likely the variability in the Langmuir probe measurements.

For the RF plasma condition, the compensation of the Langmuir probe was inadequate, causing periodicity in the IV curve. Additionally, the resonance probe results were too noisy for a detailed analysis.

No performance comparison between the diagnostics can be made. However, the resonance probe method consistently showed less variability and required less reduction than the Langmuir probe technique.

For future work:

- Determine the accuracy of the Hiden Analytical electronics.
- Examine the compensation of the Langmuir probe.
- Explore RF coaxial probe theory to predict what a resonance probe will measure in an RF plasma.