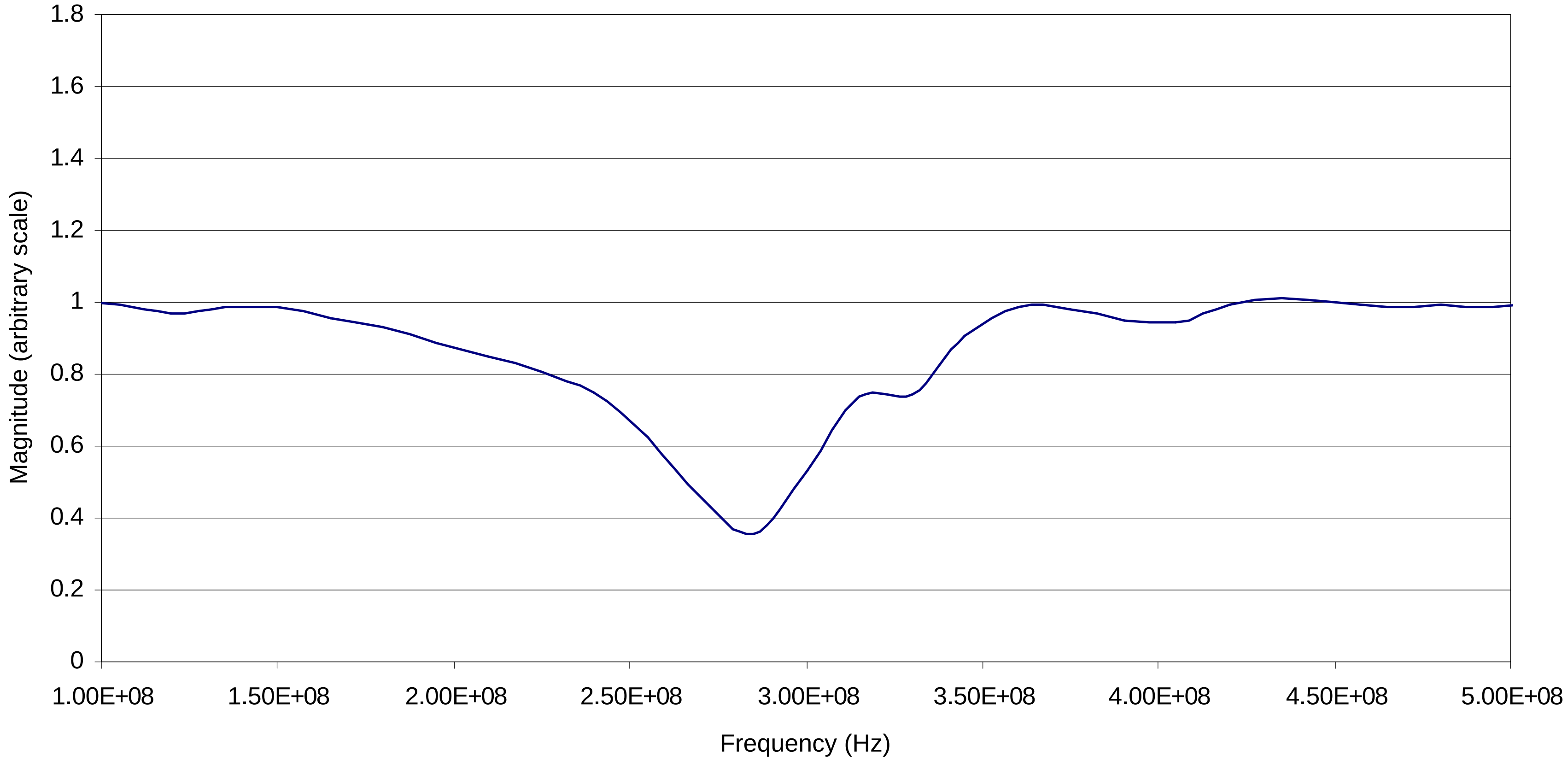
Plasma Density Measurements Inside a Laboratory Model Hall Thruster Using a Resonance Probe Diagnostic

Brian E. Beal, James M. Haas, & Alec D. Gallimore

Plasmadynamics & Electric Propulsion Laboratory

University of Michigan

Resonance Probe Trace



Plasma Models

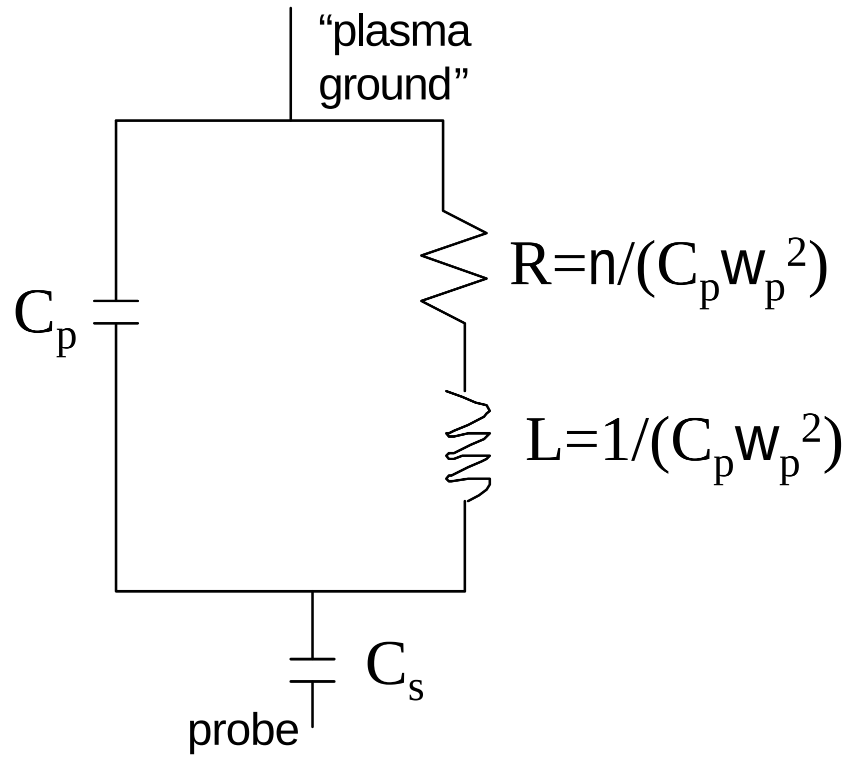
Old Model:

Resonance at upper hybrid frequency

$w_{uh}^{2}=w_{p}^{2}+w_{ce}^{2}$

$w_{p}^{2}=e^{2}n_{e}/e_{0}m_{e}$

New Model:



Resonance Formula

$$\left(\frac{w_r}{w_p}\right)^2 = \frac{(2+V) - \left(\frac{n}{w_p}\right)^2 (1+V) - \sqrt{\left[\left(\frac{n}{w_p}\right)^2 (1+V) - (2+V)\right]^2 - 4(1+V)}}{2(1+V)}$$

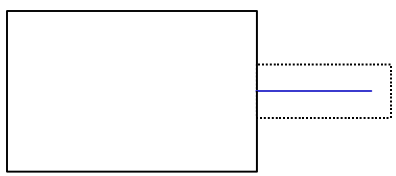
$\varsigma = C_s/C_p$

ν = electron-neutral collision frequency

w_r= resonant frequency

w_p= plasma frequency

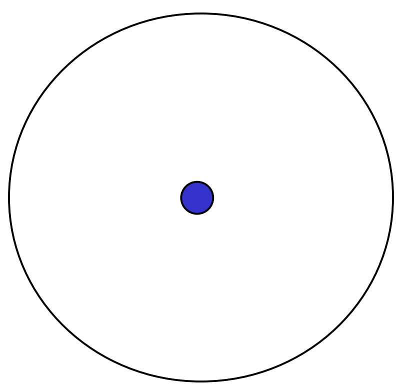
Capacitance Modeling



- Assume a thin sheath

  ~ 5 times Debye length

  $C_s=e_0A_p/s$



- Probe is small compared to bulk plasma

  Model as spherical capacitor

  $C_p = 4pe_0r$

Finding z and n

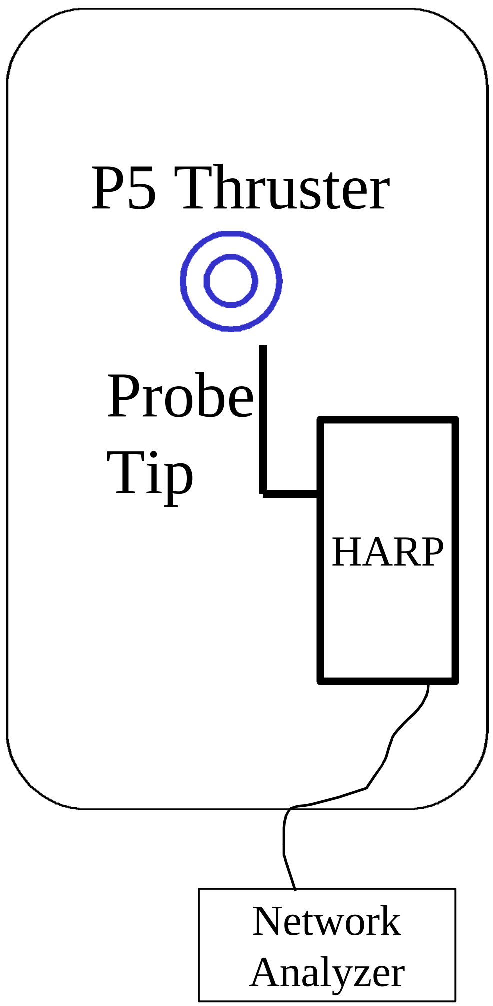
Combining the expression for the Debye length, $l_D=(e_0KT_e/ne^2)^{1/2}$, with the expressions for C_s and C_p gives:

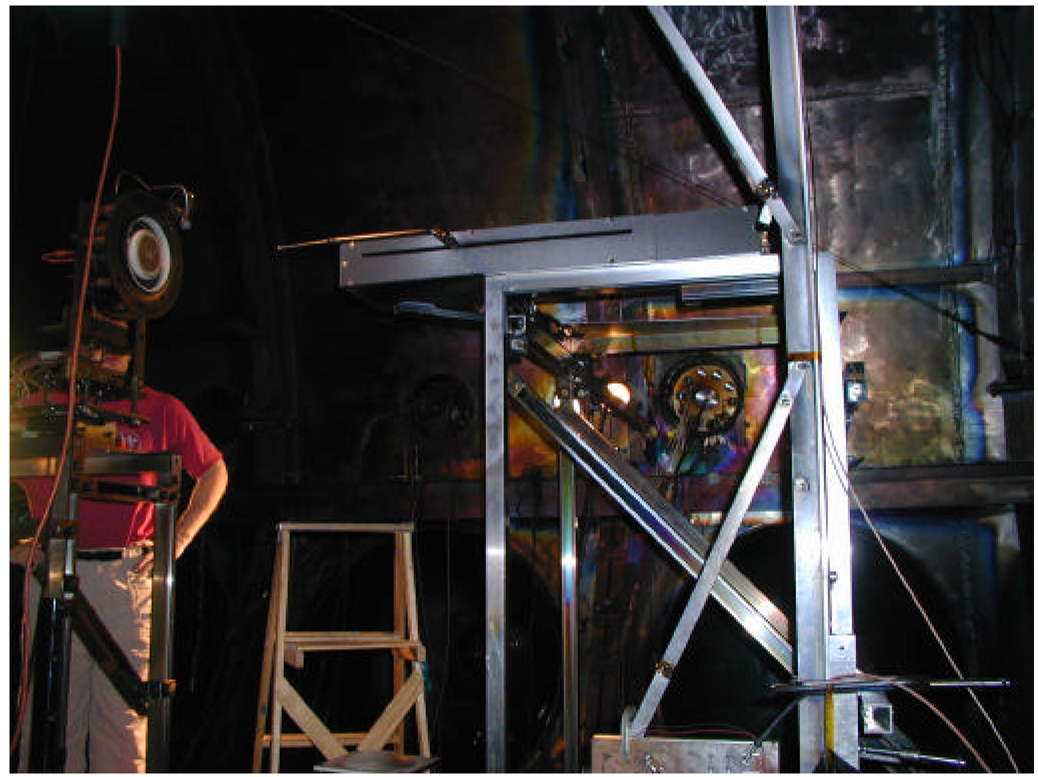
$$V = \frac{w_p}{10}\sqrt{\frac{m_e A_p}{KT_e p}}$$

The collision frequency is estimated using the half-width of the resonant peak:

$$\Delta w = \sqrt{2}n$$

Experimental Setup 1

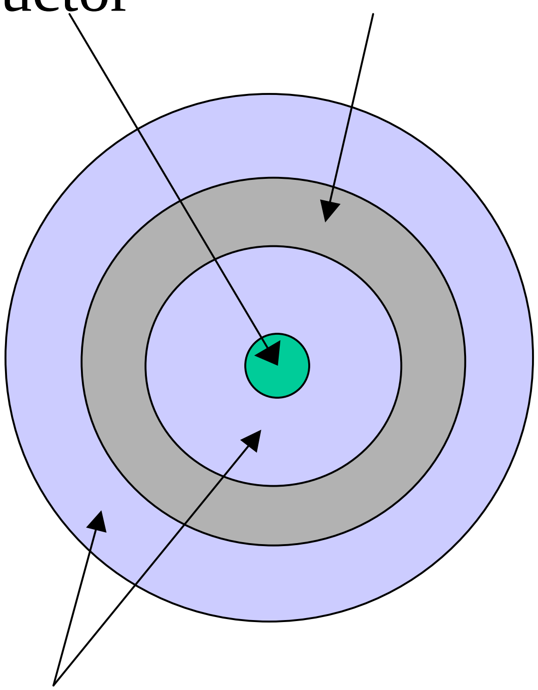




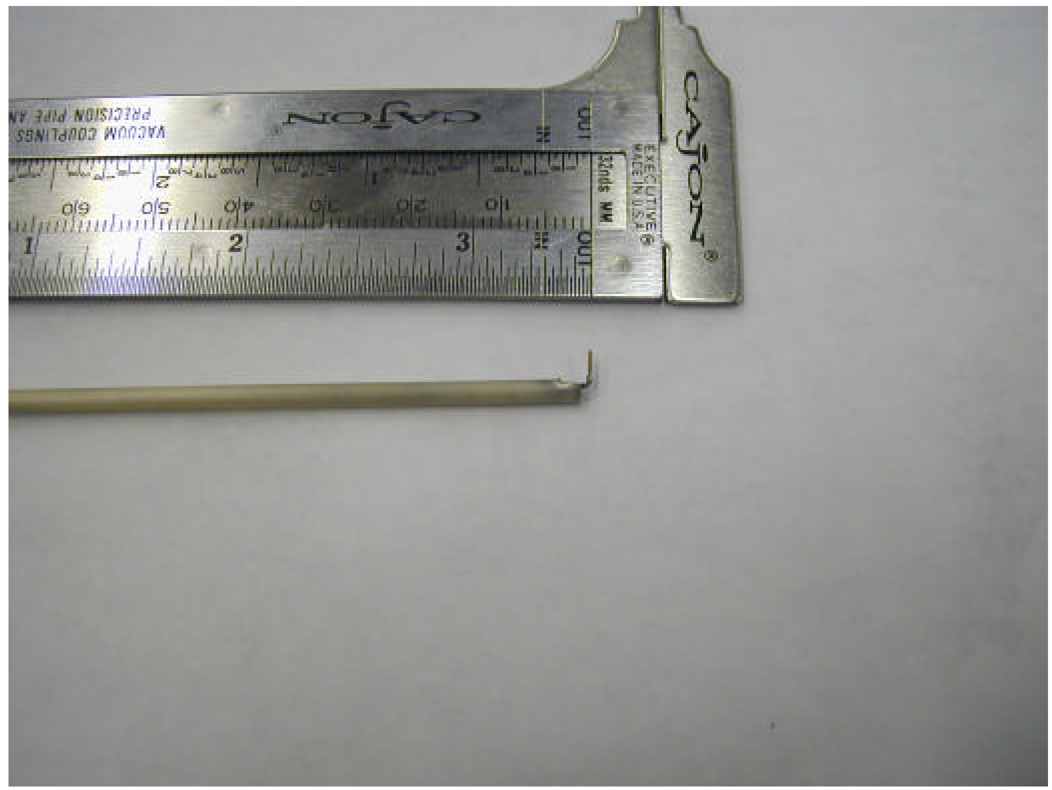
Experimental Setup 2

Tungsten
Conductor

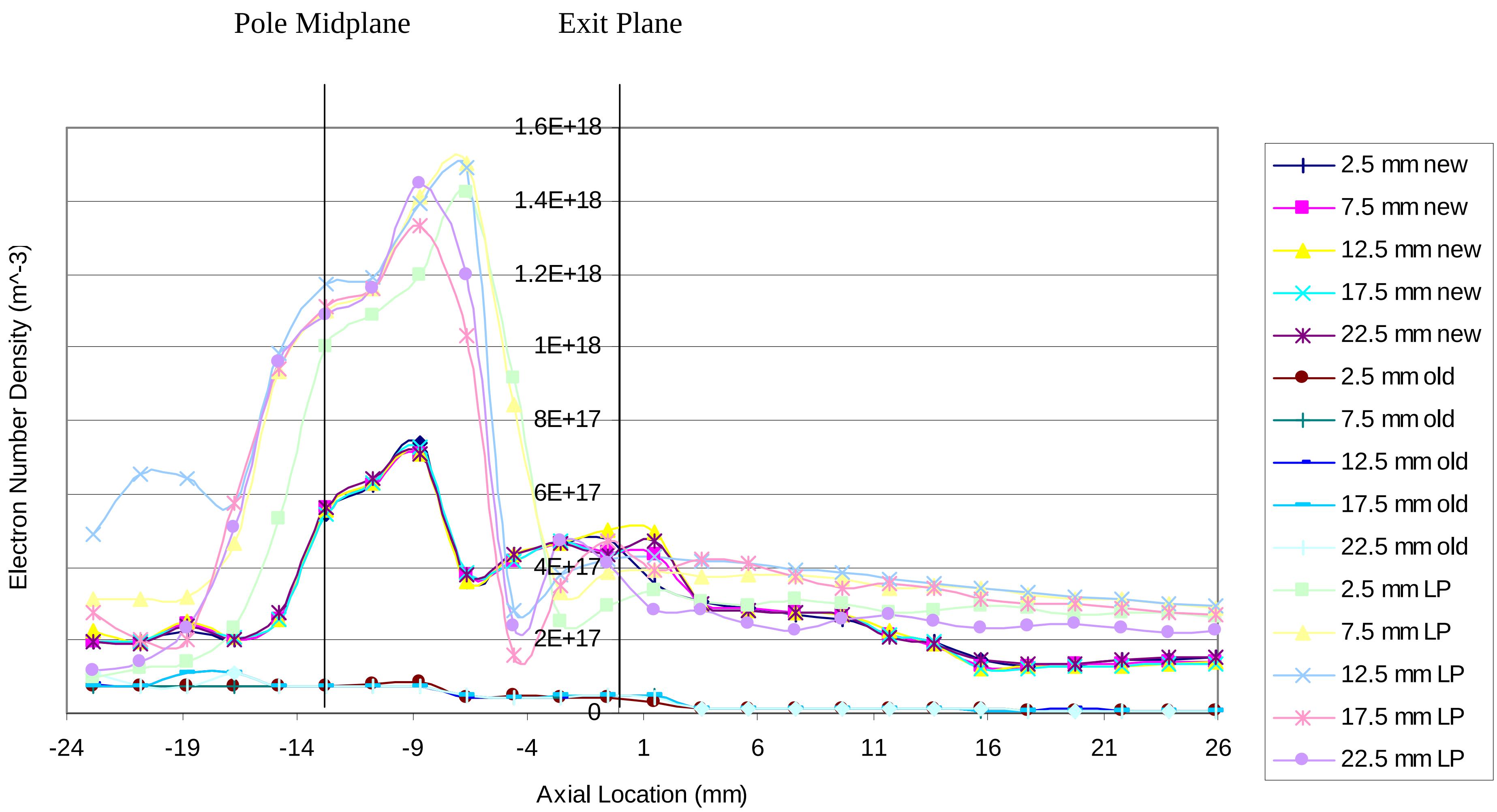
Stainless Steel
RF Shield



Alumina (Al_2O_3)
Insulator



Results



Pole Midplane
Exit Plane
Electron Number Density (m^-3)
1.6E+18
1.4E+18
1.2E+18
1E+18
8E+17
6E+17
4E+17
2E+17
0
-24
-19
-14
-9
-4
1
6
11
16
21
26
Axial Location (mm)
2.5 mm new
7.5 mm new
12.5 mm new
17.5 mm new
22.5 mm new
2.5 mm old
7.5 mm old
12.5 mm old
17.5 mm old
22.5 mm old
2.5 mm LP
7.5 mm LP
12.5 mm LP
17.5 mm LP
22.5 mm LP

Conclusions

- The resonance probe is a valuable tool for measuring plasma densities where high spatial and temporal resolution is required.
- This diagnostic can be used as a substitute for the Langmuir probe.
- It is theoretically possible to measure collision frequency, electron number density, and electron temperature with the resonance probe.