# Design and Analysis of a Retarding Potential Analyzer to Be Used for BURFIT-80 RF Ion Thruster Plume Diagnostics

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## ABSTRACT

Diagnostics of the plume plasma of electric thrusters such as ion engines and Hall thrusters used as in-space propulsion systems for satellites, provides important information about the underlying physics of the thruster operation and insight about possible thruster plume interaction with satellite operations and particle impingement on sensitive satellite surfaces. In order to determine the effects and hazards of the plume on satellite, and to examine the performance of the thruster, characterization of the plume plasma is important. Among various types of diagnostic instruments, Retarding Potential Analyzer (RPA) is a powerful one that is used for measuring the ion energy distribution of the plume plasma. The RPA data provides data about the thrust level and factors affecting the lifetime of the plasma thruster. In this study, design, material selection and manufacturing of a small (~10mm diameter) RPA to be used for an RF ion engine plume plasma diagnostics are explained. The proposed RPA will have four grids. First and second ones are the floating grids used for reducing the plasma perturbation and attenuation of the density. The third grid is negatively biased for repelling the electrons. The fourth grid is the ion-retarding grid which is positively biased by sweeping the potential between 0 to 1100V.

## DESCRIPTION & THEORY

RPA consists of a current collector and a set of biased grids and it collects the selectively filtered ions above a set limit energy by applying an ion retarding electrode potential. Plume plasma enters into device and passes through a set of grids, and reaches to current collecting surface.

The probe filters the plume constituents and allows only ions with voltages greater than the set grid voltage to reach the current collector. In other words, it removes all the electrons from the plume and selectively repels the ions that have less energy or voltage value ( V=E/q) than the ion retarding grid.

RPA has mainly four grids. First one is a floating grid used for reducing the plasma perturbation and attenuating the density in the probe. The second one is negatively biased for repelling the electrons. The third one is the ion retarding grid which is positively biased at various high values by sweeping the voltage. The fourth one is the secondary electron repeller grid which is negatively biased for preventing the secondary electrons produced by the high-energy ion collisions with the ion retarding grid and the collector from leaving the collector. The potential of this grid is below that of the primary electron repeller grid so that no electrons are trapped between these grids. And lastly, the ion collector is grounded or biased slightly negatively to attract ions.

The ion current to the collector is measured using a picoammeter since it will be in the range of $10^{-6}$ A. I-V curves are obtained by sweeping the ion retarding grid potential and recording the collected current as I versus V and later on they are fitted with smoothing splines. As the next step, the curve is numerically differentiated with respect to V and it yields the ion energy distribution. The derivative of the measured I-V characteristic is proportional to the ion voltage (energy per charge) distribution function f(V);

$$\frac{dI}{dV} = \frac{q_i^2 e^2 n_i A_c}{m_i} f(V)$$

where $q_i$ is the charge-state of the ion, e is the elementary charge, $n_i$ is the ion density, $A_c$ is the probe collection area, and $m_i$ is the ion mass.

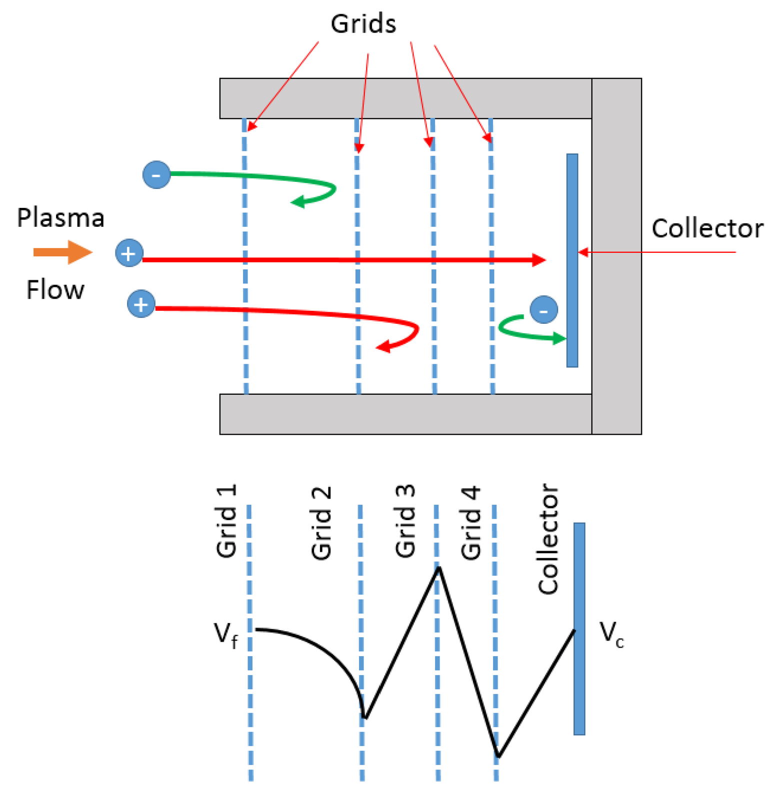


Figure: Schematic of a retarding potential analyzer and bias applied to grids.

Figure: RPA at The Plasmadynamics and Electric Propulsion Laboratory (PEPL) at the University of Michigan

## DESIGN CONCERNS

**1 Shielding Effect**

Debye length is a critical parameter for the operation of the RPA. It is related to the grid aperture size. According to the analyzer design of Hutchinson, the grid apertures should be less than thickness of the sheath (~2 $\lambda_d$) in order to minimize the shielding effect of the grids by the plasma. If the apertures are larger than the Debye length, the voltage applied for repelling the particles will not affect the plasma because it will shield itself, and the particles that are intended to repel will be able to pass through the aperture. Debye length is calculated by;

$$\lambda_d = \sqrt{\frac{\varepsilon_o k_b T_e}{n_e e^2}}$$

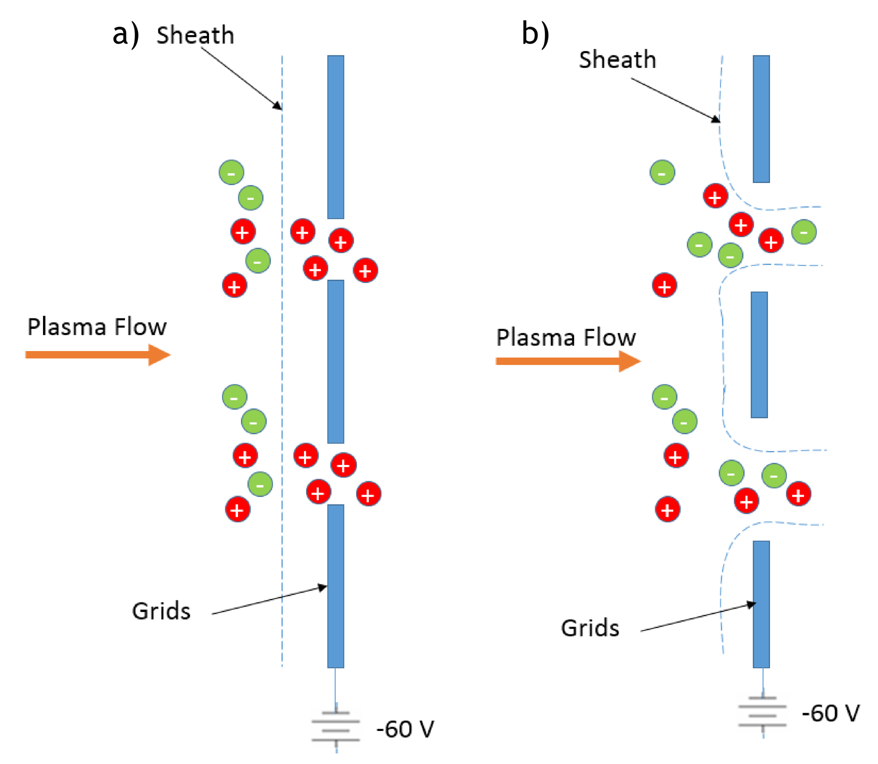


Figure: a) Grid opening < sheath thickness
b) Grid opening > sheath thickness

**2 Space Charge Effect**

The electron repeller grid will repel all the electrons and allow the ions to pass, if the aperture size is less than the sheath. After passing through the electron repeller grid, since all the particles in the region between electron repeller and ion repeller grid are ions, ion charge density causes a rise in the potential between the grids. This phenomenon is called space charge effect. It shifts the potential to a higher level than the potential that is supplied by power supply. If this is the case, ions will be affected by the repulsive potential hill and wil be repelled by the highest potential which leads to low current measurements. The proper spacing between two grids should be calculated in order to avoid this limitation by Hutchinson's derivation of the relation for the grid spacing and Debye length;

$$\frac{x}{\lambda_d} = 1.02\left(\frac{eV}{kT_e}\right)^{\frac{3}{4}}$$

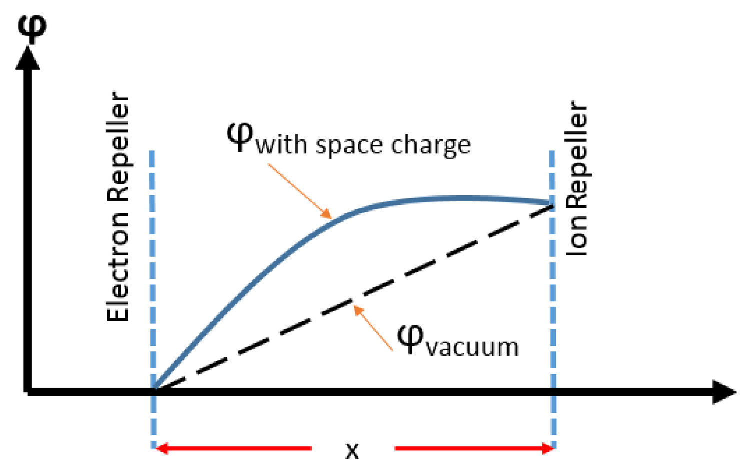


Figure: Graphical representation of the space charge effect

**3 Ram Pressure**

Another problem arises when the large flux of particles enters from the large probe entrance to internal volume of the probe and "chokes" the cavity of the probe due to increased pressure inside. Entering ions are neutralized by the collisions with the wall and the collector and the relatively dense gas inside the probe scatters the incoming ions because of the both momentum and charge exchange (CEX) collisions. The collisions in the probe will destroy energy information. The result is an attenuation and broadening of the ion energy distribution. So this criterion puts a limit to the operation pressure range. It is possible to overcome this limitation by the use of differential pumping and decreasing the pressure inside the probe; so the lower pressure leads to an increase of the mean free path to a larger value that makes the collisions negligible consequently.

## BUSTLAB RPA DESIGN

Required data for designing the RPA is obtained from RIT-10 plume data since RIT-10 is the most similar thruster to BURFIT-80 due to its size, beam voltage and current (beam power). This probe is designed to operate at 100 mm - 500 mm axial distance on the thruster exit centerline where the electron temperature and electron density are approximated as 1.8 eV and $1\times10^{17}$ m$^3$ respectively. The design is completed based on these values.

Setting the feasible spacing between electron and ion repeller grids to 1 mm, with Green's relation;

$$n \leq \frac{4\varepsilon_o E_i}{9e^2 x^2}$$

it is found that maximum density in the probe should be around $2.36\times10^{15}$ m$^3$. It means that, the density should be attenuated at least 42 times in order to prevent space charge effects in the region of highest density. So double entrance grid is designed. The first and second grids are designed to have a transmission of 10% and 20% respectively. So the combined attenuation of 50 is obtained.

Considering that the Debye length with the reduced density is 0.28 mm, 0.3 mm is chosen for the aperture diameter.

For impact energies below 1 keV, the secondary electron emission yield of copper is less than 0.1 electrons per ion. Considering the low electron emission from the collector and the molybdenum grids, the secondary electron suppression grid is omitted in order to maximize the open area fraction of the grid system and ensure an adequate signal to noise ratio.

Electrical connections are made by spot welding them to the grids and they are aligned between the sleeve's outer edge and inner edge of the casing and exiting at the back of the probe.

Figure: The Spacer Thicknesses

| Spacer No | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Thickness | 1 mm | 1 mm | 3 mm | 1 mm | 3.5 mm | 6.5 mm |

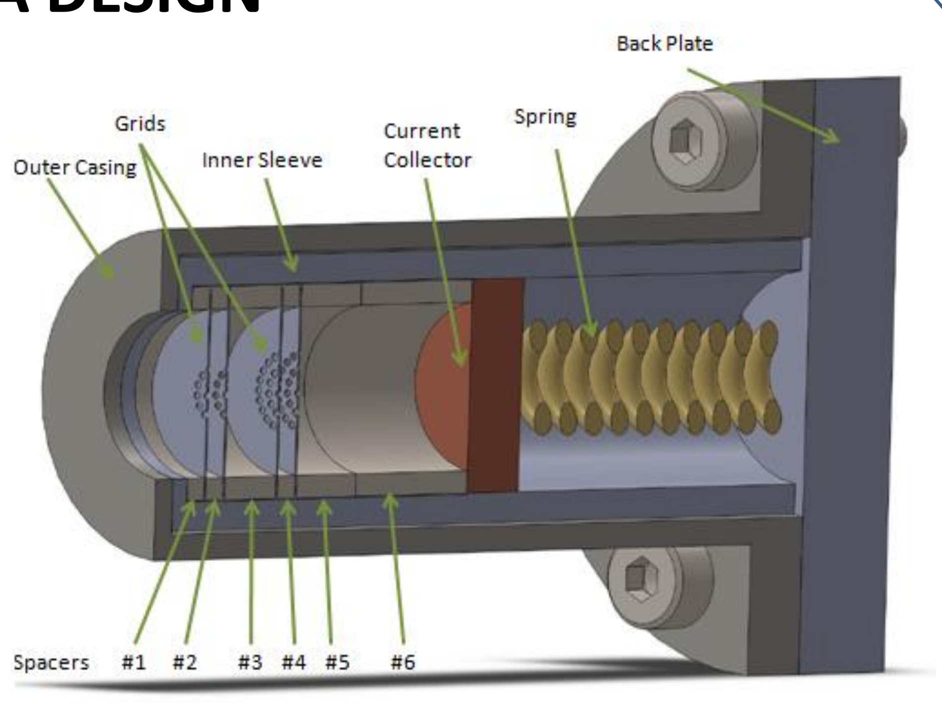


Figure: 3D Retarding Potential Analyzer (RPA)

| Part | Material | Size | | |
|---|---|---|---|---|
| Outer Casing | 316 SS | O.D 12.7 mm | I.D. 10.7 mm | Length 38 mm |
| Inner Sleeve | Boron Nitride | O.D. 10.5 mm | I.D. 8.8 mm | Length 36.5 mm |
| Spacers | MACOR | O.D. 8 mm | | |
| Grids | Molybdenum | O.D. 8 mm | Thickness 0.1 mm | |
| Collector | Copper | O.D. 10.5 mm | Thickness 3 mm | |
| Electrical Wires | Copper | 30 AWG (0.255mm) | | |

Figure: Parts' Information

## PROBE SETUP AND DATA INTERPRETATION

The probe will be placed at various distances downstream of the exit of the thruster and will be swept between various angles within the limits with a stepper motor movable bench for having results all around the plume.

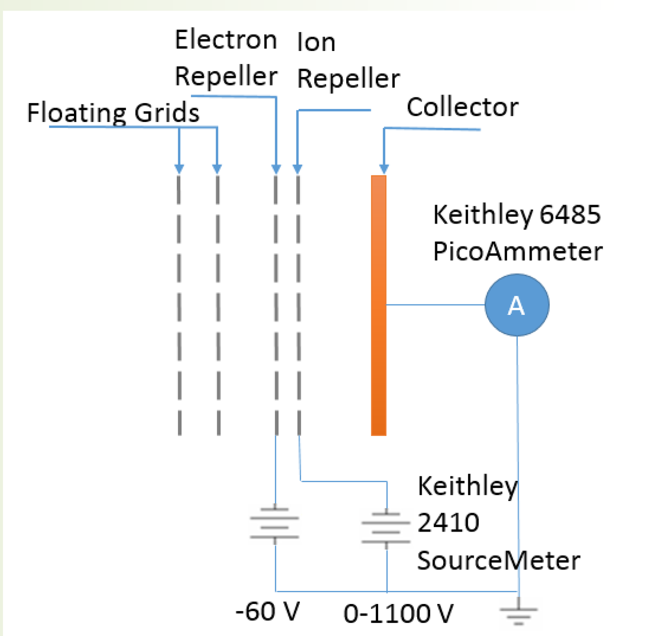


Figure: Electrical schematic of the RPA

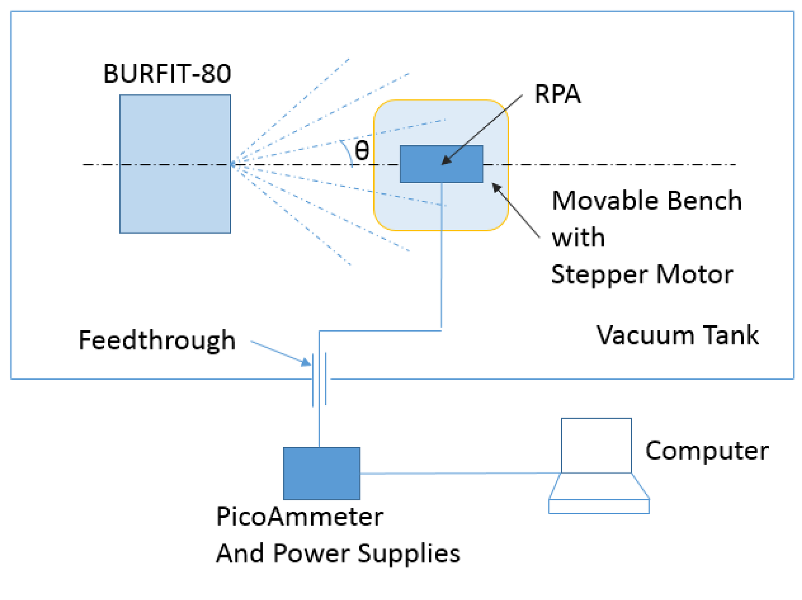


Figure: Probe setup in the vacuum tank

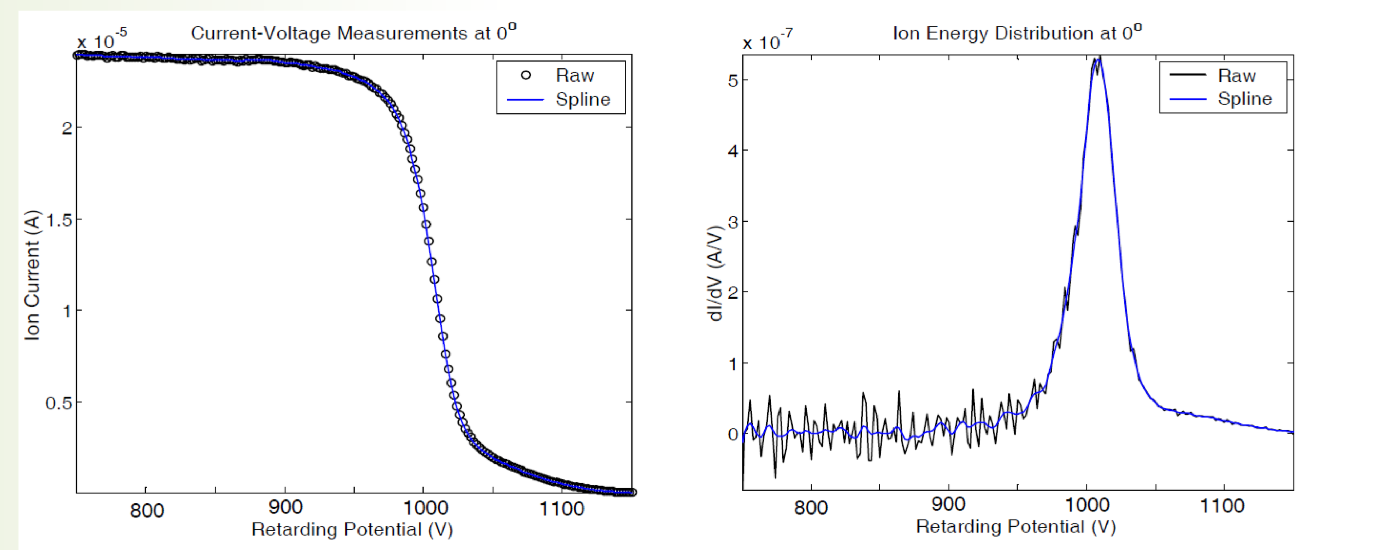


Figure: Expected I-V curve and ion energy distributions

A Maxwellian distribution will be obtained. The peak point can be interpreted as primary ion energy. Expected primary ion energy will be around 1000 eV since the accelarater grid of the BURFIT-80 is biased to 1100 V.

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