Thermal Plasma Instrumentation for CubeSat Missions

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The Retarding Potential Analyzer (RPA) technique is one of the oldest and best validated approaches to space plasma thermal ion measurements. The first RPA flew on Sputnik 3.

RPAs built by UT Dallas have flown on a large number of satellite experiments, including AE, DE, DMSP, ROCSAT-1, and C/NOFS.

One reason for the popularity of RPAs is their ability to measure more independent thermal plasma parameters than any other single space science instrument, including:

- Ion drift speed along the satellite’s orbit track
- Ion temperature ($T_i$)
- Ion density ($N_i$)
- $\Delta N_i/N_i$
- Ion composition
RPA Operating Principle

The RPA must be mounted on the satellite in a ram-facing configuration.

The aperture, shield, and suppressor grids are held at constant potentials, as is the solid plate collector.

The retarding grids are swept over a range of positive values. As the retarding voltage increases the flux of positive ions to the collector is reduced.
Quantitative Analysis

• Since the spacecraft is moving at ~7.5-8 km/s, an O$^+$ ion that is stationary in the Earth frame will have ~8x10^{-19} J of kinetic energy in the satellite frame.

• A potential $\Phi = mV^2/2e \approx 5$ volts applied to the retarding grids will prevent such an ion from reaching the collector inside the RPA.

• Ions that are moving toward the spacecraft will require somewhat larger stopping voltages, and those that are moving away from the spacecraft will be stopped by smaller retarding voltages.

• Light ion species, such as H$^+$, will also have lower stopping voltages.
An IV Curve for an $N_2^+$ Plasma with a Maxwellian Distribution
IV Curve Analysis

The IV curves look different depending on the ion composition, density, ram velocity, and temperature of the ambient plasma medium.

Fitting routines allow us to infer these parameters from the curves.
DMSP Data for a Two-Species Case

IV Characteristic - DMSP Satellite at 850 km

Collector Current (nA) vs. Retarding Grid Potential (Volts)
Simulations of Grid Effects in the RPA

- **Problem:** Ions distributions are distorted by the grid wires because of the non-uniform potential fields they produce.

- The distorted distributions produce errors in the inferred parameters, but in some cases these errors can be understood and mitigated.

- **Solution:** Numerical simulations of these effects for different grid geometries can help us design better RPAs (Davidson *et al.*, Phys. Plasmas, 2010).
Simulation Approach

These contours show the potential distributions within a single square grid cell for 3 different geometries. The voltage step between contours is the same for all plots.

Using Simion™, ion trajectories are mapped as they progress through the grids. Simulated IV curves created in this way are analyzed using the same types of curve fitting routines that are used for interpreting flight data.

Since the initial simulated distributions are known, errors arising from the different grid geometries can be calculated & compared.
Grid Induced Density Errors

![Graph showing the relationship between Temperature (k) and Density Error (%). The graph includes three lines representing Flat, Woven, and Double Thick materials.](image_url)
The UTD CubeSat RPA

CAD studies coupled with the use of surface mount leadless components have enabled us to create a CubeSat-sized version of the UTD-RPA.

The engineering model unit shown here has been designed for easy assembly, so that it can be mass produced for multi-satellite missions.
CubeSat RPA Specifications & Requirements

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<thead>
<tr>
<th>Parameter</th>
<th>Size</th>
<th>Mass</th>
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<tbody>
<tr>
<td>RPA Sensor &amp; Housing</td>
<td>9.6 x 9.6 x 6.0 cm</td>
<td>0.6 kg</td>
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<tr>
<td>Boards &amp; Connectors</td>
<td>9 x 9 cm</td>
<td>0.05 kg</td>
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**Parameter Specification**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Pointing Accuracy</td>
<td>±1-5° for $T_i$ and $N_i$ measurements</td>
</tr>
<tr>
<td>Pointing Knowledge</td>
<td>±0.1-0.5° for $V_{ram}$ measurement</td>
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<tr>
<td>Spatial Resolution</td>
<td>8-30 km depending on bit rate</td>
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<tr>
<td>Bit Rate</td>
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Conclusions

• The RPA technique is one of the most reliable approaches to obtaining in-situ space plasma data, and it will continue to be useful for future space situational awareness missions.

• The flight-proven RPA built by UTD for previous large-satellite missions has been successfully adapted for flight on CubeSat-sized satellites.

• Recent numerical studies have provided design guidelines and better understanding of the errors inherent in the RPA technique, and how to mitigate them.