Low SWaP Sweeping Langmuir probe for orbital and sub-orbital platforms mitigating spacecraft charging

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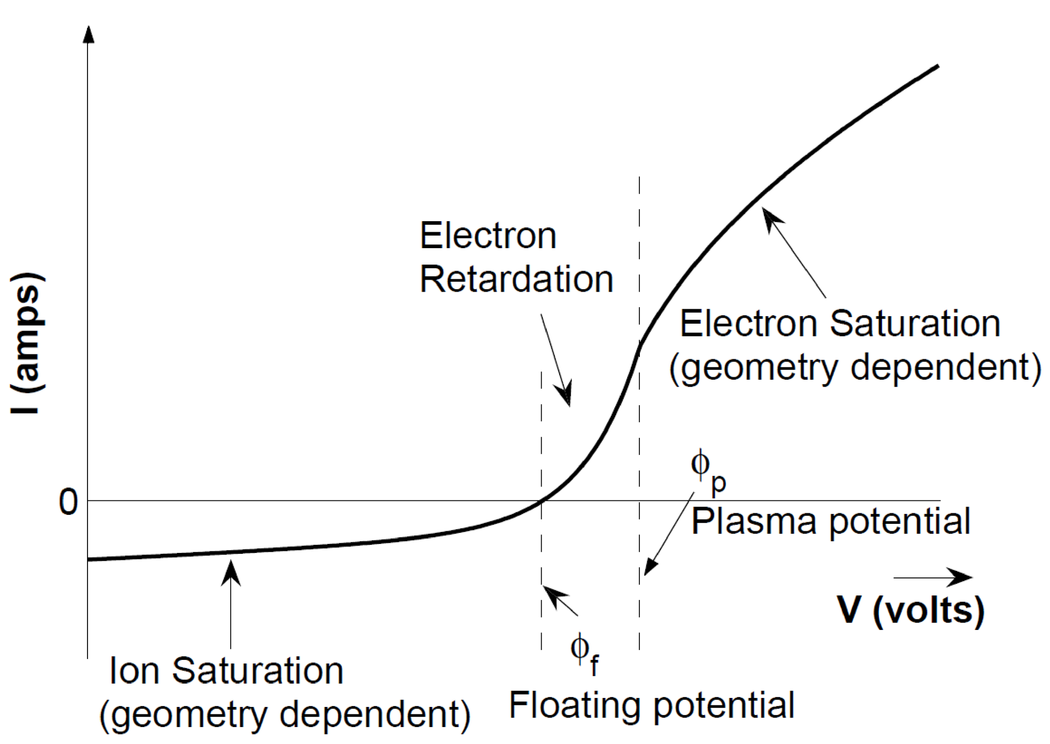
Abstract

Electron temperature (Te) is a fundamental plasma parameter that is critically important for understanding a variety of plasma phenomena. For thermal plasmas this is typically measured using a Sweeping Langmuir Probe (SLP). Operating a SLP on a spacecraft where the surface area ratio of spacecraft-to-probe is less than 1000 results not only in erroneous Te measurement, but it also dynamically swings the spacecraft floating potential (i.e. spacecraft charging) with every sweep and inadvertently affects other electrostatic instruments on the spacecraft. With the continued miniaturization of spacecraft, such as CubeSats, and the growing need to be able to do measurements from a constellation of such small spacecraft, it is now imperative to build an instrument that can circumvent the dynamic charging made by an SLP and yet accomplish accurate Te measurements.

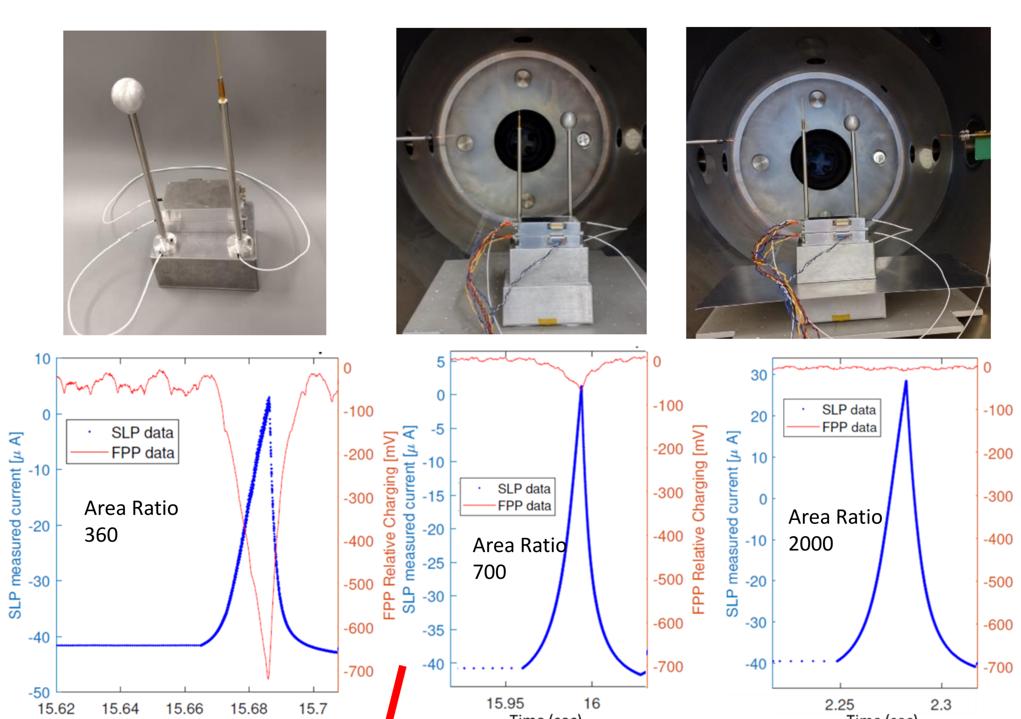
The Space and Atmospheric Instrumentation Laboratory at Embry-Riddle Aeronautical University has developed a small form factor miniature Double Langmuir Probe (mDLP) that enables high sample rate observations of plasma density and electron temperature from orbital and suborbital platforms. The instrument is a dual-sensor Langmuir probe that can be operated in high cadence fixed bias mode to give plasma density and also run in a swept bias mode to give electron temperature without swinging the payload floating potential. The circuit enforces equal and opposite current balance to each electrode to mitigate spacecraft charging. This is accomplished during a voltage sweep by biasing the electrodes with respect to each other, instead of a spacecraft ground, and allowing the bias voltages of the electrodes to float as needed to achieve current balance. The probe can be fitted with planar or cylindrical probes, of similar or asymmetric surface areas to increase the sampled regions of the I-V curve of the desired measurement. This work will present some bench and plasma chamber results of the novel instrument.

Langmuir Probe Background

In-situ plasma parameters can be determined through the use of a Sweeping Langmuir Probe (SLP). Sweeping a voltage bias on an electrode immersed in plasma and measuring the resultant current yields an IV curve (right) from which one can determine electron and ion density, and electron temperature. The IV curve characteristics are dependent on probe geometry, wherein current collected by cylindrical, spherical, and planar probes increases with applied potential in differing shapes in the Electron Saturation region. Accounting for the geometry of the sensor and fitting to this curve yields plasma density and temperature.

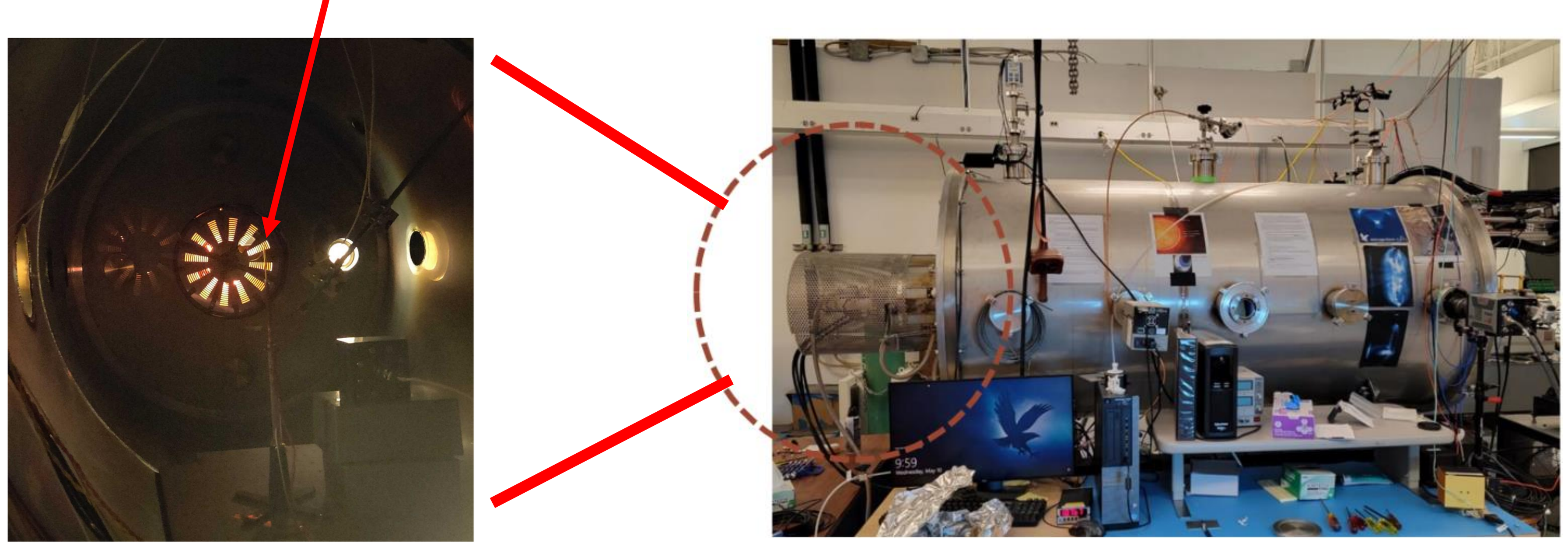


Example Single Element Sweeping Langmuir Probe (SLP) Current and Voltage (IV) Curve. [1]

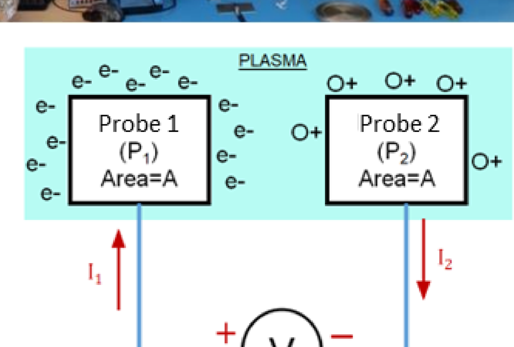


The analysis of a SLP depends on the knowledge of the return current for a given bias voltage, but even more importantly on the applied voltage with respect to some *fixed* reference. In the case of many instances, Earth Ground or Spacecraft Ground is sufficiently stable for this reference. However, if the current collected from a Sweeping Probe is unable to be infinitely sunk to the reference ground, then the probe bias potential will also change the reference potential, adversely effecting the SLP measurements (and potentially other instruments).

Sweeping Langmuir probes require a ratio of vehicle surface area to probe area of greater than 10,000 to avoid charging the spacecraft with every sweep, examples of these charging effects seen left in the SAIL plasma chamber. [2]



In order to mitigate this effect, a Double Sweeping Probe can be constructed as outlined on the right. Instead of a bias voltage swept with respect to the spacecraft ground, the bias potentials on two sensors are swept with respect to on another, and the center of the bias differential is allowed to drift with respect to spacecraft ground, until net 0 current is achieved.

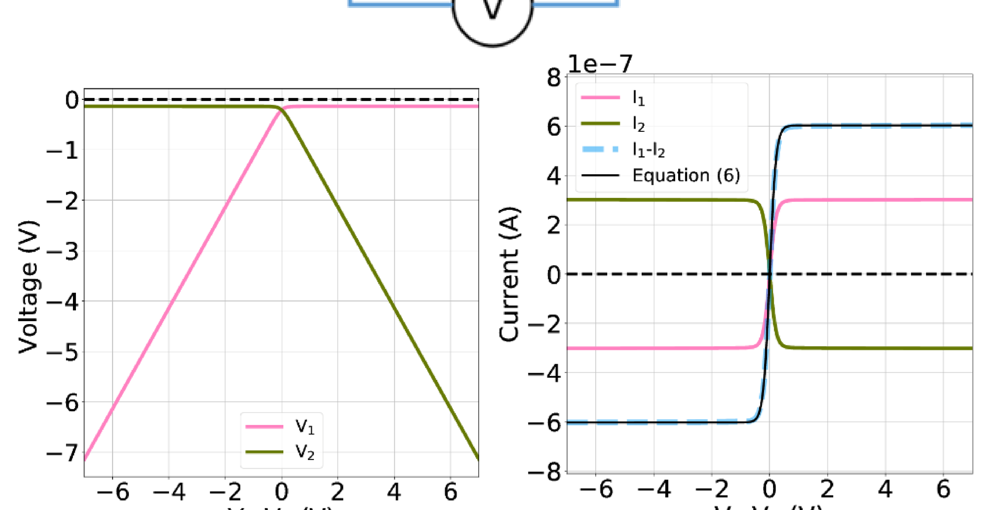


Plotting the differential voltage against the recorded current (simulated, right) results in a similar IV characteristic curve, which can be fit to determine plasma density and temperature.

$$C(S) = 2I_{beta}\tanh\left(\frac{S}{2k_bT_e}\right)$$

$$I_{beta} = I_{thermal,i}\left(1+\frac{S}{2k_bT_e}\right)^{\beta}$$

Simulated Result for Beta = 0, LEO orbit, fixed ram current

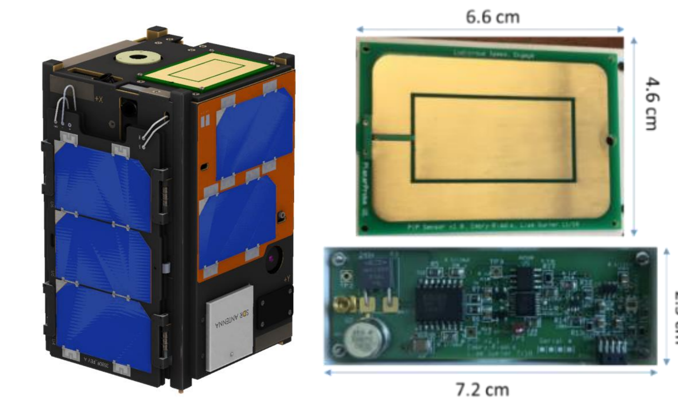


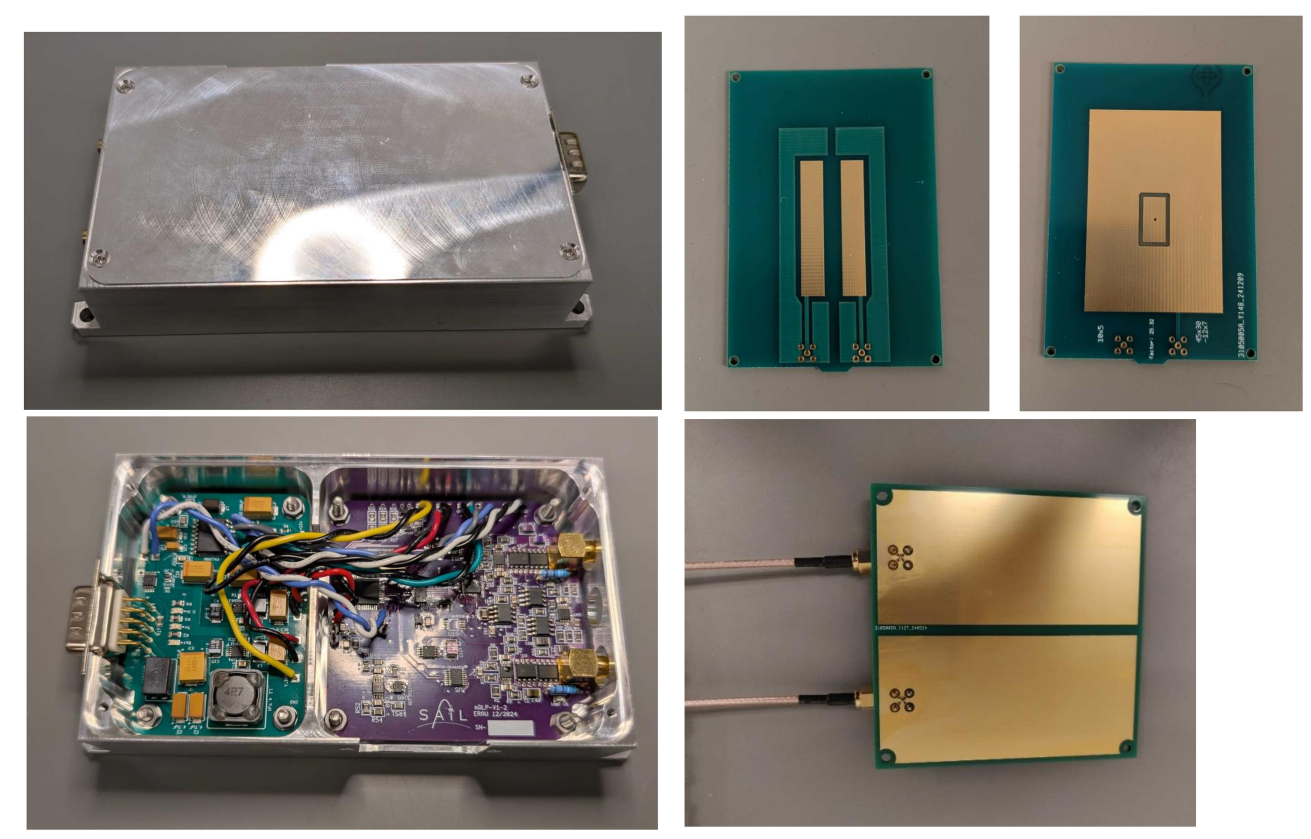
mini-Double Langmuir Probe (mDLP)

Double Probe Instrument design based on form factor and probe sizes of LLITED spacecraft (right). LLITED fixed bias PIP seen Right.

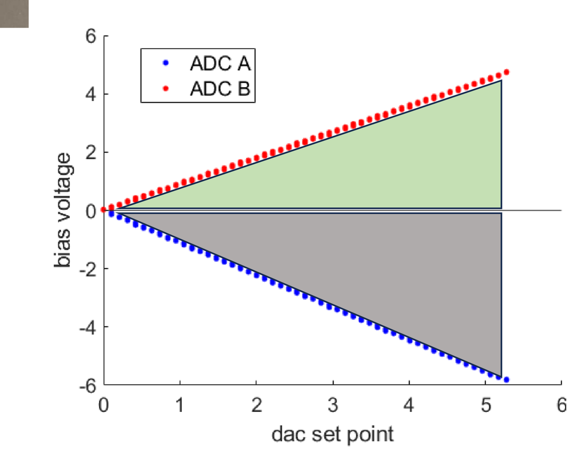
Low SWaP Electronics, ~300g and <2W power consumption under operation. Approximate 5”x3”x1” size for electronics box.

Electronics available as radiation tolerant variants for all critical parts.

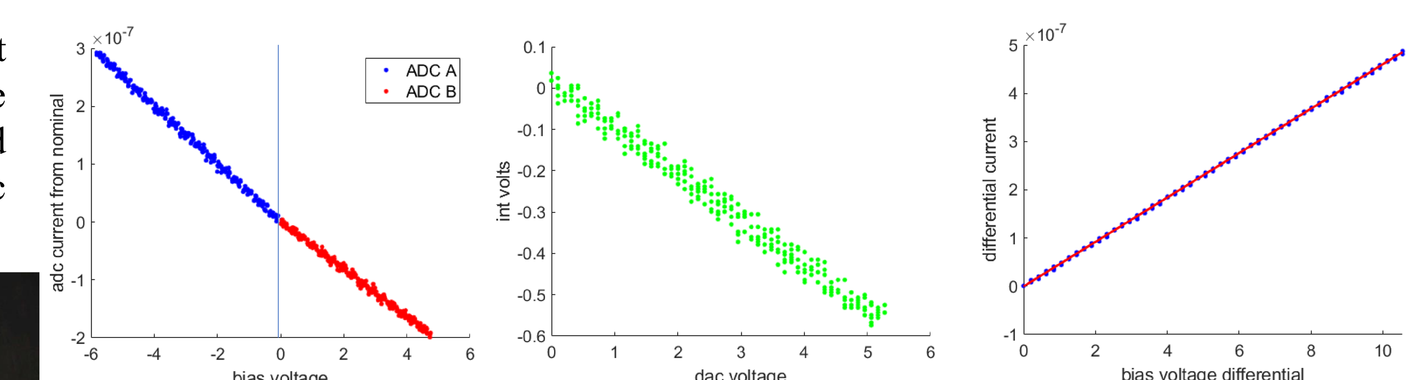


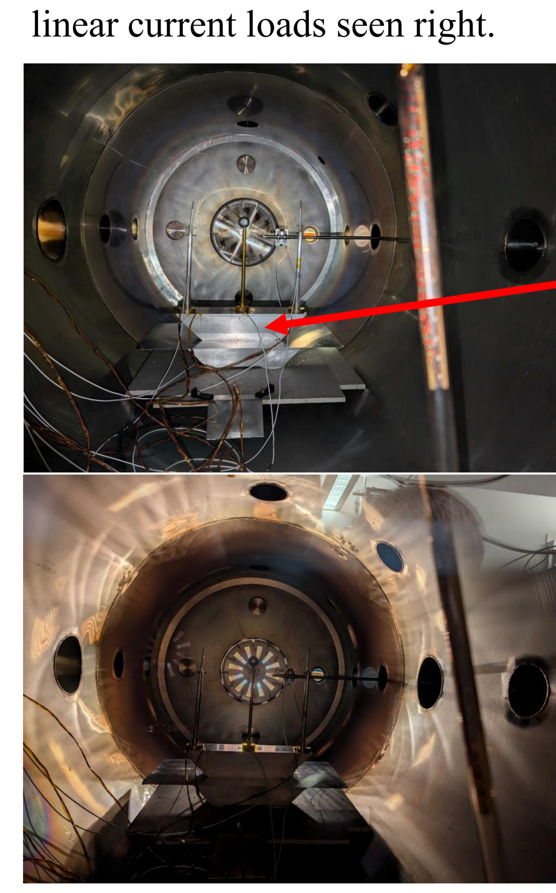


Variety of Sensor geometries for input to double probe under evaluation. Simulated probe behavior modeled in NASCAP, instrument tested in SAIL Plasma Chamber. Example planar designs shown left.



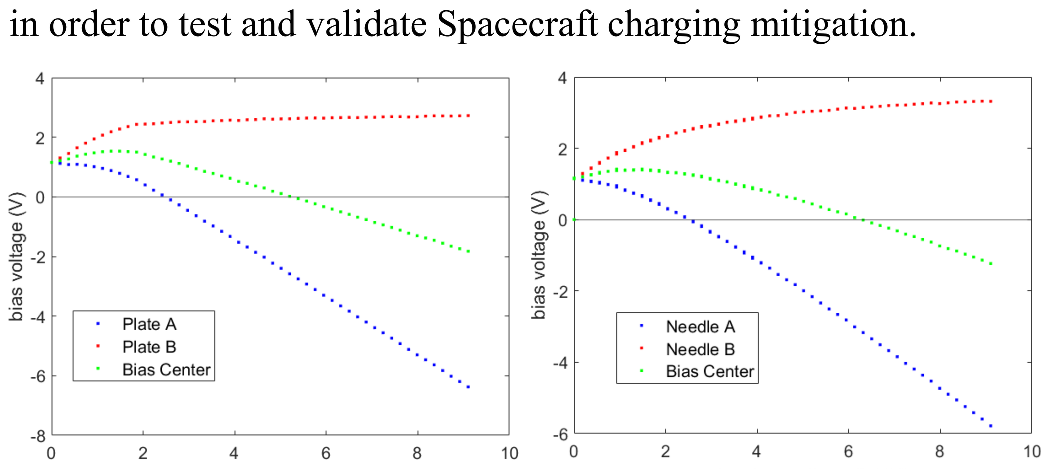
Bench testing of mDLP circuit with resistor loads to sample plate designs. Bias voltage and current balance with asymmetric linear current loads seen right.



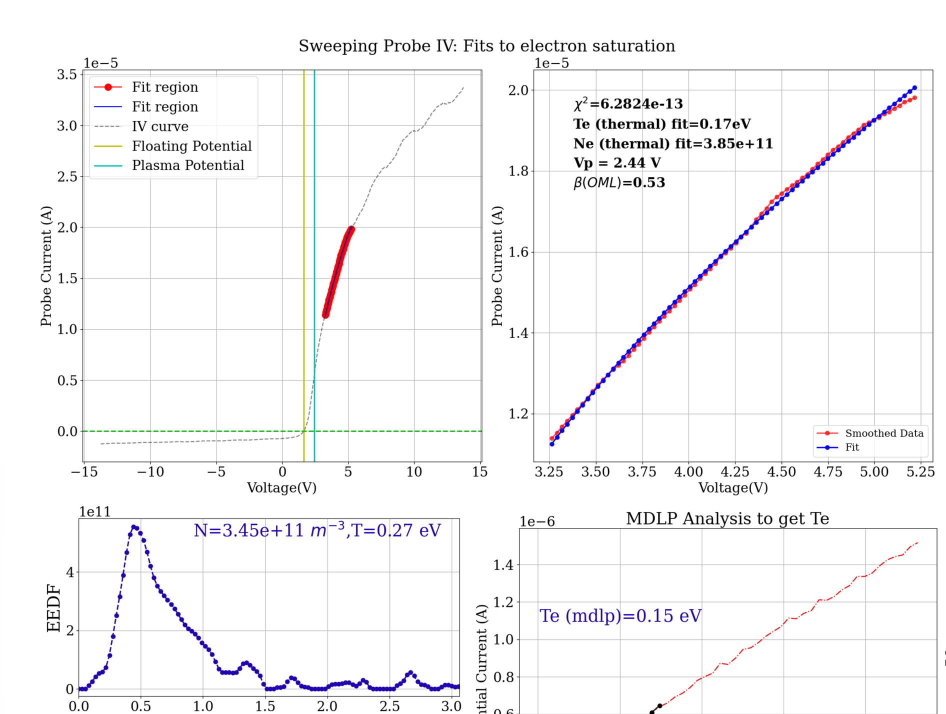


Instrument installed onto isolated “Spacecraft” in SAIL Plasma chamber, and sampled with standard SLP, mDLP, and Floating Potential measurements taken at the same time as sweeping probes in order to test and validate Spacecraft charging mitigation.

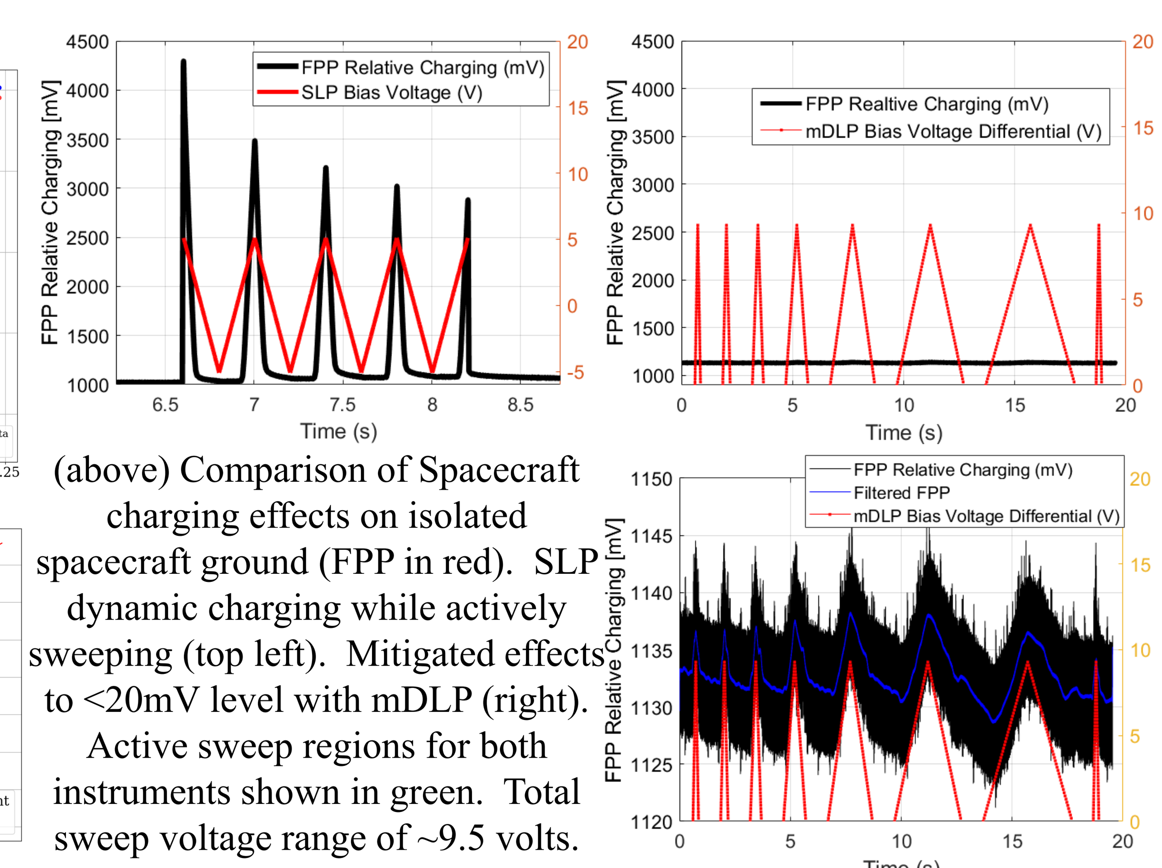
Spacecraft set with dual planar and needle inputs. Needle inputs sampled with SLP and mDLP for comparison. FPP Sphere seen in center of spacecraft monitoring floating potential. Difference in planar and cylindrical probe behavior seen right in mDLP inputs.



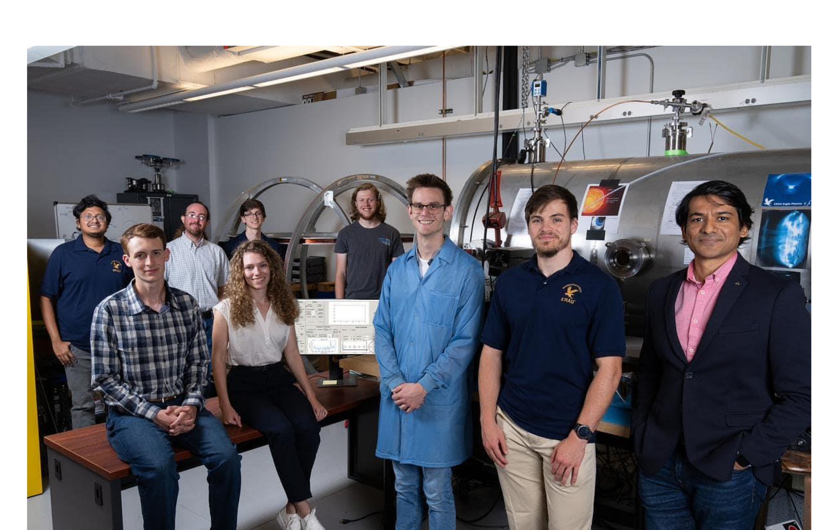
(above) Monitoring effect of bias potential offsets for different dual-probe geometries. Absolute voltages in blue/red, offset potential to balance current input in green.



(above) Comparison of density and temperature fits from mDLP and verifying instruments.



(above) Comparison of Spacecraft charging effects on isolated spacecraft ground (FPP in red). SLP dynamic charging while actively sweeping (top left). Mitigated effects to <20mV level with mDLP (right). Active sweep regions for both instruments shown in green. Total sweep voltage range of ~9.5 volts.



Conclusion

- Sweeping Double Probe design has been built and tested in ERAU Plasma Chamber.
- Operation shows mitigated Spacecraft charging while sweeping, and generates curve fits of similar values to other in-situ instruments.
- Ongoing design work for modifying instrument for Cubesat form factor.
- Preparation for the upcoming Science flight on the Resolute Sounding Rocket mission.

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References

[1] Barjatya, A., *Langmuir Probe Measurements in the Ionosphere*, PhD thesis, Utah State University, (2007).
[2] Oreo, Anthony, "Design, Development, and Calibration of an Electric Field Probe for Use on Sounding Rockets" (2022). *Doctoral Dissertations and Master's Theses*. 654.