USE OF A LANGMUIR PROBE INSTRUMENT ON BOARD A PICO-SATELLITE

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ABSTRACT

The sweeping Langmuir probe instrument, which includes four thin cylindrical probes whose electrical potential is swept to measure both plasma density and electron temperature together with the spacecraft potential, is part of the payload of PICASSO, an ESA in-orbit demonstrator. PICASSO is a triple unit CubeSat of dimensions 340.5 x 100 x 100 mm. The orbit is expected to be a high inclination low Earth orbit. The main issue implied by the use of a pico-satellite platform for a Langmuir probe instrument is the limited conducting area of the spacecraft, which leads to spacecraft charging and drift of the instrument's electrical ground during the measurement. A specific measurement technique that includes the simultaneous measurement of the potential and current of different probes has been developed to retrieve consistent current-voltage characteristics that can be used to estimate the plasma parameters mentioned above.

1. PICASSO MISSION

PIC.A.S.S.O. (PICo-satellite for Atmospheric and Space Science Observations) is a scientific CubeSat-based project initiated by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) in 2010. It was successfully proposed to the Belgian Scientific Policy Office and to ESA as an In-Orbit Demonstrator of scientific applications from LEO CubeSats. The objective of the PICASSO mission is to demonstrate the capacity of low-cost nano-satellites to perform remote and in-situ scientific measurements of physico-chemical properties of the Earth's atmosphere. In addition to these, PICASSO also aims to bring the instruments and the on-board data processing components to high technology readiness levels in order for them to be incorporated in future scientific missions with a reduced risk.

The satellite is built upon a 3U CubeSat platform (340.5 x 100 x 100 mm, 1U for payload), featuring four deployable solar panels, UHF/VHF and S-band communications, two on-board computers, a high performance ADCS and two scientific instruments for ESA-grade science data: VISION (Visible Spectral Imager for Occultation and Nightglow) and SLP (Sweeping Langmuir Probe).

The satellite shall be launched in 2017 into a high inclination low-Earth orbit, at about 500 km – 550 km altitude and will have a lifetime of at least 1 year.

The scientific objectives of VISION are:

- Polar and mid-latitude stratospheric ozone vertical profile retrieval
- Upper atmosphere temperature profiling based on the Sun refractive flattening

The scientific objective of SLP is the in-situ study of:

- Ionosphere-plasmasphere coupling
- Subauroral ionosphere and corresponding magnetospheric features
- Aurora structures
- Turbulence (multi-scale behaviour, spectral properties)

The expected plasma parameters along the orbit of PICASSO are given in Tab 1.

Table 1. Expected plasma parameters

	Minimum (> 95% probability)	Maximum (> 95% probability)
Plasma density (#/m³)	10^8 (10^9)	10^{13} ($5x10^{12}$)
Electron temperature (K)	600 (700)	10 000 (5 000)
Debye length (m)	5.4e-4 (8.2e-4)	0.69 (0.15)

2. SLP INSTRUMENT

SLP is a 4-channel Langmuir probe instrument. Its measurement principle is based on the conventional Langmuir probe theory [1]. By sweeping the potential of a probe with respect to the plasma potential while measuring the current from this probe, the instrument will acquire a current-voltage characteristic from which the electron density and temperature, ion density and S/C (spacecraft) potential are retrieved. The measurements are performed in three regions: ion saturation, electron retardation and electron saturation regions. A typical current-voltage characteristic of such a probe is illustrated in Fig. 1. The ion density is derived from the ion saturation region, where the potential of the probes is sufficiently negative to repel electrons and attract only ions. The electron temperature and S/C potential are retrieved from the electron retardation region, where the potential of the probes is close to that of the plasma so that both ions and electrons are attracted. The electron density is derived from the electron saturation region, where the potential of the probes is sufficiently positive to repel ions and attract only electrons.

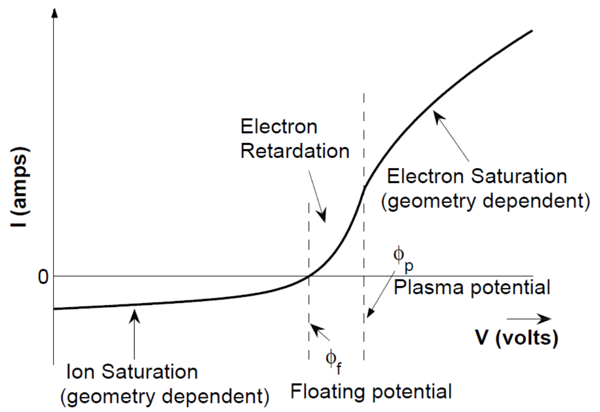

Figure 1. Typical Langmuir probe current-voltage characteristic

In nominal mode, SLP sweeps the potential of the probes from -5 V to +13 V with respect to the S/C potential in order to retrieve the electron density and temperature, together with the S/C potential and the ion density (when it is large enough). In another mode, the instrument measures only in the electron saturation region at a higher rate, measuring electron density with better spatial resolution. This later operating mode is based on the principle described in [2]. Although the telemetry is limited, the raw data will be downloaded to the ground because the measured current-voltage characteristics contain more information than only four parameters (electron density and temperature, ion density and S/C potential). For instance, in auroral regions multicomponent plasmas can be present, which require much more sophisticated analysis to derive the plasma parameters.

The four probes are mounted on the deployable solar panels, which act as deployable booms, as depicted in Fig. 2. This configuration ensures that at least one probe is out of the S/C wake at any time, in addition to providing redundancy.

The probes are 40 mm long Ti tubes of 2 mm diameter. They are attached to the extremity of the solar panels via a 40 mm long boom, as depicted in Fig. 3. The sampling frequency is fixed at 10 KHz and the maximum sweeping frequency is about 50 sweeps/s.

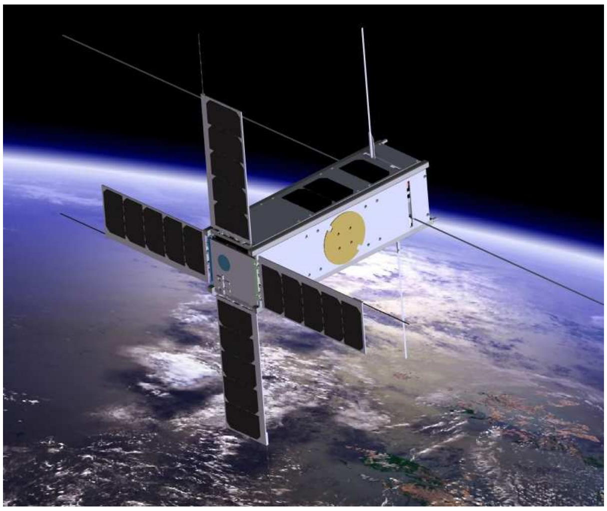

Figure 2. SLP probes on PICASSO

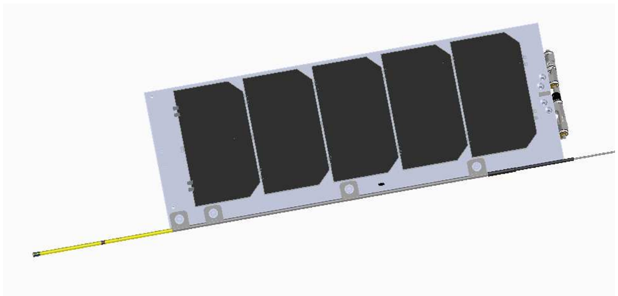

Figure 3. Probe and boom (in yellow) at the extremity of the solar panel

3. LIMITATION OF PICO-SATELLITE PLATFORM AND PROPOSED SOLUTION

One of the main issues implied by the use of a pico-satellite platform for a Langmuir probe instrument is the limited conducting area of the S/C. Because the conducting area of the S/C is not large enough compared to the area of the probes, the S/C will charge negatively when the probes are swept with positive bias. This charging will lead to a drift of the S/C potential during the sweep, making the data unusable. There is also the risk that the potential of the S/C drops so much that the probes cannot be biased to measure properly in the electron saturation region.

In order to avoid this problem, a specific measurement technique which uses two different probes simultaneously has been developed: while one probe is biased and measure the current (traditional Langmuir probe technique) a second probe is used to measure the floating potential. By combining the measured floating potential with respect to the S/C potential and the probe potential with respect to the S/C potential (applied bias), the probe potential with respect to the floating potential can be known. Therefore, consistent current-voltage characteristics can be retrieved.

In addition, to ensure that probes can sweep properly in the electron saturation region all along PICASSO orbit, the conducting surface of the S/C has been increased to have at least 200 cm² on all sides of the S/C, including the solar panels.
The main advantage of this technique is that there is no need for an electron gun. This is particularly important since the filament of electron guns have usually limited lifetime and PICASSO shall operate for at least one year.
To investigate and quantify the charging of the S/C, two types of simulation have been performed: particle-in-cell (PIC) and electric circuit simulations.

3.1. PIC Simulations

The PIC simulations have been performed with SPIS. The model is a conductive cube of 14.14 cm length side, leading to 200 cm² conducting area per side, as required for PICASSO. The probe is modelled as a 40 mm long cylinder of 2 mm diameter. To limit the computation time, the boom and solar panel are not modelled, as can be seen in Fig. 4. An example of the potential distribution at the surface of the S/C and the surrounding plasma is shown in Fig. 5. It can be seen that when 6.5 V is applied to the probe (with respect to the S/C potential) the probe is at about 2.5 V with respect to the plasma and the S/C chassis is at about -4V with respect to the plasma.

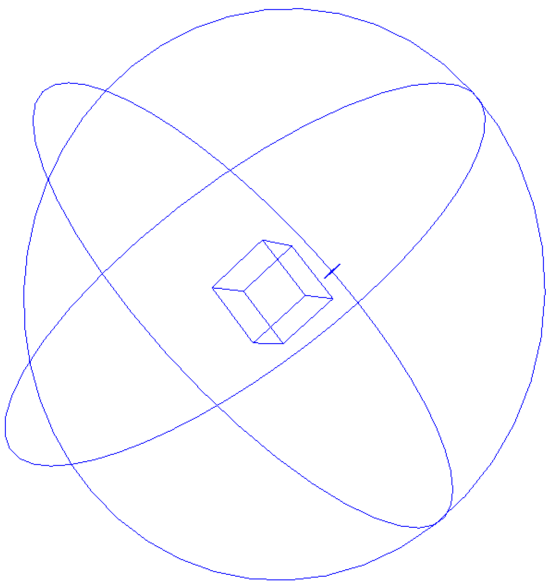

Figure 4. SPIS model with one probe

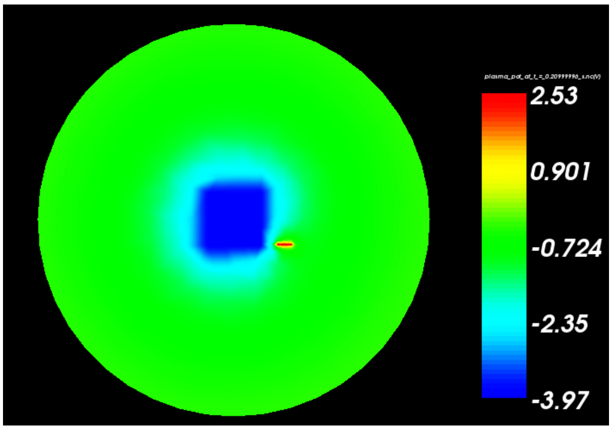

Figure 5. Potential distribution at the surface of the S/C and the surrounding plasma. Applied bias voltage: 6.5 V

3.2. Electric Circuit Simulations

The electric circuit model is shown in Fig. 6. The coupling between the probe and the plasma is modelled by an R-C circuit. The fact that the current due to the collection of ions is different from the current due to the collection of electrons is taken into account by having in parallel two resistors in series with a diode (the two diodes are in opposite directions). The two probes (the one that is biased and measures the current and the one that measures the floating potential) are modelled in the same way and with the same values of resistors and capacitors. The coupling between the S/C chassis and the plasma is also modelled with an R-C circuit, similarly to the probes, but with different values. The values of resistors and capacitors used in the simulations are based on measurements performed in a plasma chamber, where the electron density was about $2x10^{11}/m^3$ and the electron temperature was about 600 K.

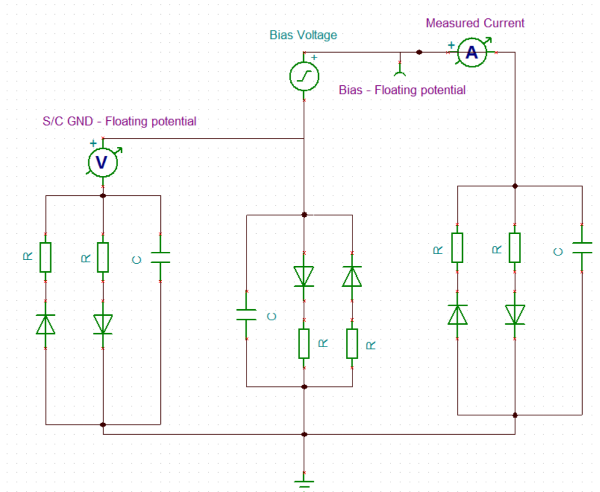

Figure 6. Electric circuit model

It can be seen in Fig. 7 that as the bias applied to the probe (with respect to the S/C potential) increases, the

S/C potential decreases and the potential of the probe with respect to the plasma potential reaches only 3.85 V instead of 13 V.

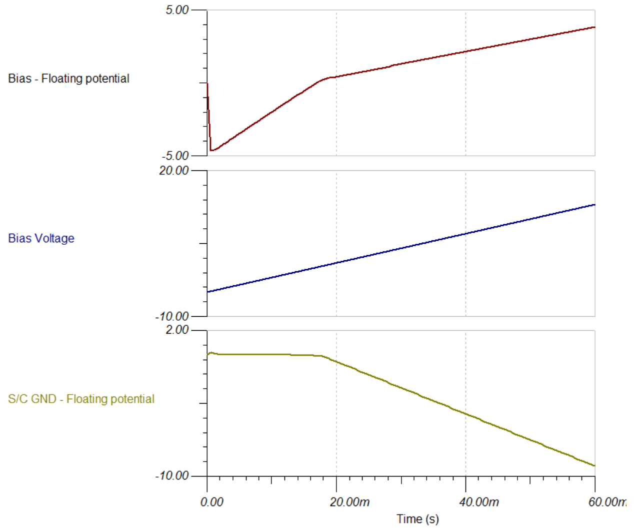

Figure 7. S/C and probe potential with respect to the plasma potential as a function of the applied bias at the probe

4. CONCLUSIONS

The sweeping Langmuir probe instrument, which includes four thin cylindrical probes whose electrical potential is swept to measure both plasma density and electron temperature together with the spacecraft potential, is part of the payload of PICASSO, a triple unit CubeSat of dimensions 340.5 x 100 x 100 mm.
The main issue implied by the use of a pico-satellite platform for a Langmuir probe instrument is the limited conducting area of the spacecraft, which leads to spacecraft charging and drift of the instrument's electrical ground during the measurement. A specific measurement technique that includes the simultaneous measurement of the potential and current of different probes has been developed to retrieve consistent current-voltage characteristics that can be used to estimate the plasma parameters mentioned above. Particle-in-cell (PIC) and electrical circuit simulations have been performed to analyse and quantify the charging of the spacecraft.

5. REFERENCES

1. Merlino R. L. (2007). Understanding Langmuir probe current-voltage characteristics, Am. J. Phys. 75(12), 1078-1085, DOI: 10.1119/1.2772282.
2. Bekkeng, T. A. et al. (2010). Design of a multi-needle Langmuir probe system, Meas. Sci. Technol. 21 085903