Use of a Langmuir Probe Instrument on Board a Pico-Satellite

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***Abstract*— The sweeping Langmuir probe instrument is a part of the payload of PICo-satellite for atmospheric and space science observations (PICASSO), an ESA in-orbit demonstrator. It includes four thin cylindrical probes whose electrical potential is swept to measure both plasma density and electron temperature together with the spacecraft (S/C) potential. PICASSO is a triple unit CubeSat of dimensions 340.5 mm × 100 mm × 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 S/C, which leads to S/C 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.**

***Index Terms*— CubeSat, Langmuir probe, plasma physics, spacecraft (S/C) charging.**

I. Introduction

PICo-SATELLITE for atmospheric and space science observations (PIC.A.S.S.O.) 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 Low Earth orbit (LEO) CubeSats. The objective of the PICASSO mission is to demonstrate the capacity of low-cost nanosatellites to perform remote and *in situ* scientific measurements of physicochemical properties of the earth's atmosphere. In addition, PICASSO also aims at bringing the instruments and the on-board data processing components to high technology readiness levels to allow them to be incorporated in the future scientific missions with a reduced risk.

The satellite is built upon a 3U CubeSat platform (340.5 mm × 100 mm × 100 mm, 1U for payload) featuring four deployable solar panels, ultra high frequency/ very high frequency (VHF) and *S*-band communications, two on-board computers, a high-performance ADCS and two scientific instruments for ESA-grade science data: 1) visible spectral imager for occultation and nightglow (VISION) and 2) sweeping Langmuir probe (SLP).

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TABLE I
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)

The satellite shall be launched in 2018 into a high inclination low-earth orbit, at about 500–550 km altitude and will have a lifetime of at least one year.

The scientific objectives of VISION are the following:

1) polar and mid-latitude stratospheric ozone vertical profile retrieval;
2) upper atmosphere temperature profiling based on the Sun refractive flattening;

the scientific objective of SLP is the *in situ* study of:

1) ionosphere–plasmasphere coupling;
2) subauroral ionosphere and corresponding magnetospheric features;
3) aurora structures;
4) turbulence (multiscale behavior, spectral properties).

The expected plasma parameters along the orbit of PICASSO are given in Table I.

The SLP instrument is described in Section II. The limitation of pico-satellite platform for Langmuir probe instrument and the proposed solution are presented in Section III. Section IV concludes this paper.

II. SLP Instrument

SLP is a four-channel Langmuir probe instrument. Its measurement principle is based on the conventional Langmuir probe theory [1]. By sweeping the potential of a probe with

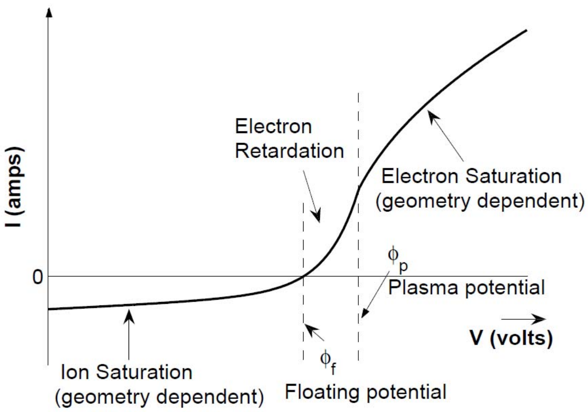

Fig. 1. Typical Langmuir probe current–voltage characteristic.

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 spacecraft (S/C) potential are retrieved. The measurements are performed in three regions: 1) ion saturation; 2) electron retardation; and 3) 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.

In nominal mode, SLP sweeps the potential of the probes from -5 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 (where it is high enough). The sampling frequency is fixed at 10 kHz and the maximum sweeping frequency is about 50 sweeps/s. The limited downlink bandwidth does not allow performing linear voltage sweeps with very fine steps in nominal mode. Instead, the three regions (ion saturation, electron retardation, and electron saturation) are measured with different step sizes. Ion and electron saturation regions are measured with large voltage step size (>1 V). The electron retardation region is measured with smaller step size, which depends on the electron temperature: this region is measured with 30 steps, but the span is adapted as a function of the temperature. On board, the inflection point of the I–V curve which separates the electron retardation and electron saturation regions (the plasma potential) is determined after each sweep and used to compute the span of the electron retardation region of the next sweep. The step size ranges from about 10 to 150 mV for electron temperatures of 600 and 10 K, respectively.

In another mode, the instrument measures only in the electron saturation region at a higher rate, measuring electron density with better spatial resolution in order to resolve fine plasma structures like those presented in [2]. This later operating mode is based on the principle described in [3]. 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 requires more sophisticated analysis to derive the plasma parameters [4].

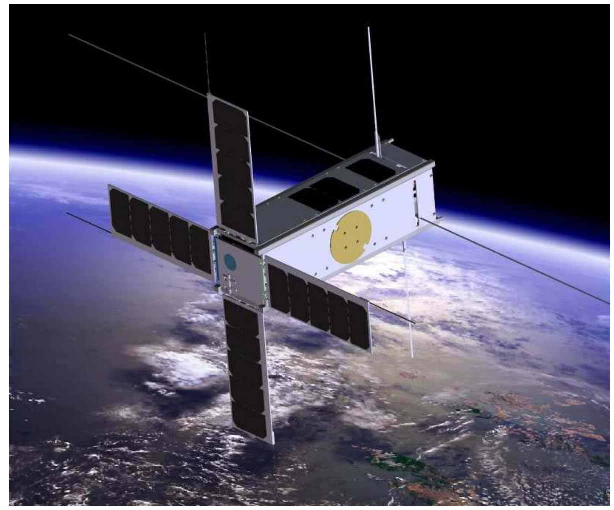

Fig. 2. SLP probes on PICASSO.

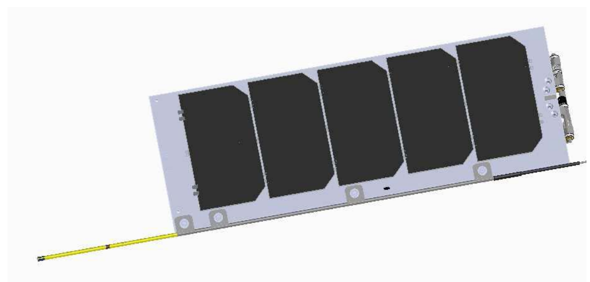

Fig. 3. Probe and boom (in yellow) at the extremity of the solar panel.

The four probes of SLP 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.

Due to constraints related to the diameter of the probe and coax cable as well as the mechanical complexity inside the probe and boom, it was not possible to include a guard on the probe. Furthermore, a guard would increase the collecting area which would make the S/C charging effect more severe. The effect of the absence of guard on the I–V curve will be quantified during tests in a plasma chamber at a later stage.

There will be no active on-orbit cleaning of the probe surface. First, since PICASSO will fly on a high-inclination orbit, it is expected that natural ion and electron sputtering will occur at high latitude, where the S/C will encounter energetic ions and electrons. This natural sputtering seemed to be sufficient for several Langmuir probe instruments which did not show signs of contamination (Tiros-7, Explorers 17, 22, 23, 31, 32, Alouette-II, ISIS-1 and ISIS-2) [5]. Furthermore, for a significant part of the orbit, the temperature of the probe should reach about 200 °C which should help cleaning [6]. Finally, an active on-orbit cleaning would have significantly increased the complexity of the instrument and create additional constraints.

III. 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 as 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 measures 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. 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 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 cm^2 on all sides of the S/C, including the solar panels, leading to 1200 cm^2 conducting surface area for the whole S/C. Given that the collecting area of the probe is about 2.5 cm^2, the ratio of total S/C collecting area to total probe collecting area is 472. The solar cells themselves are not coated and therefore do not participate to the S/C collecting area.

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. Although the size of PICASSO with deployed Langmuir probes is small enough to fit into some plasma chamber, it was not possible to test the proposed solution due to time and budgetary constraints.

A. PIC Simulations

The PIC simulations have been performed with spacecraft plasma interaction system (SPIS). SPIS can be used to study charging in geosynchronous earth orbit, LEO, or other environments, taking into account surface physics (e.g., secondary emissions, photo-emission, and surface and volume conductivity) and volume physics (e.g., electrostatic, electromagnetism, kinetic or fluid description, and collisions). The model is a conductive cube of 14.14-cm length side, leading to 200 cm^2 conducting area per side, as required for PICASSO. The probe is modeled as a 40-mm-long cylinder of 2-mm diameter. To limit the computation time, the boom and solar panel are not modeled, 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 −4 V with respect to the plasma.

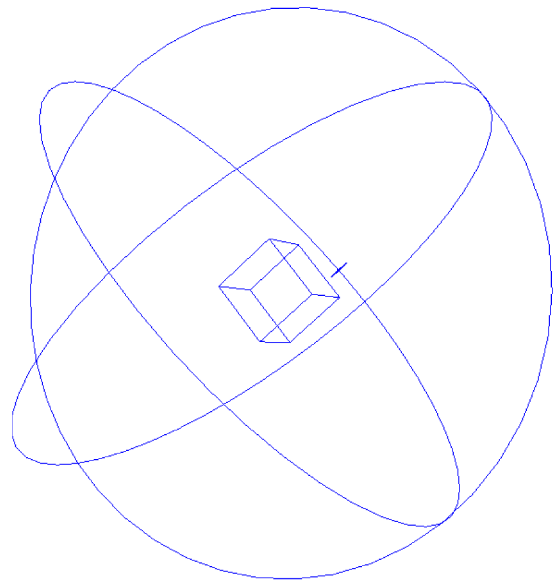

Fig. 4. SPIS model with one probe.

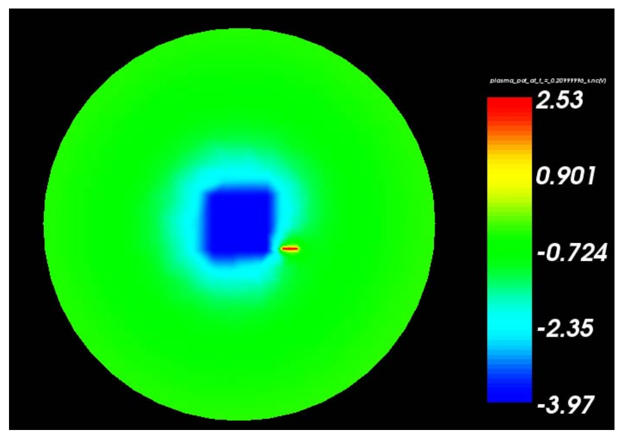

Fig. 5. Potential distribution at the surface of the S/C and the surrounding plasma. Applied bias: 6.5 V.

The effect of S/C charging on Langmuir probe measurement is illustrated in Figs. 6 and 7, where 6- and 13-V bias steps are applied to the probe. It can be seen that the S/C potential is significantly affected by the Langmuir probe instrument and that the potential of the probe with respect to the plasma potential changes substantially during each step, making the measurement meaningless if the S/C potential is not known during the sweep.

To ensure that probes can sweep properly in the electron saturation region all along PICASSO orbit, SPIS simulations

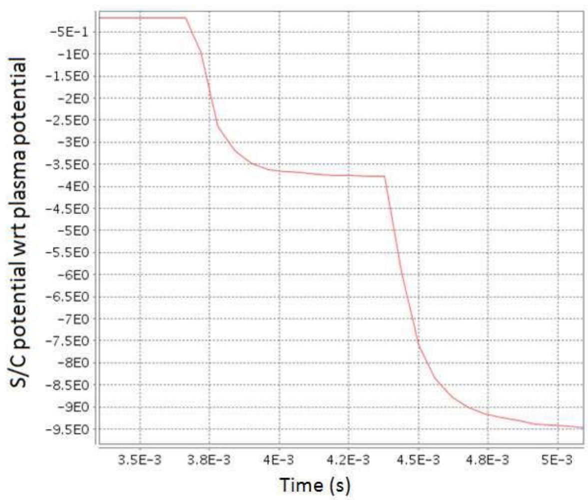

Fig. 6. S/C potential with respect to the plasma potential when 6- and 13-V steps are applied to the probe. Electron density and temperature are set to $10^{11}/\text{m}^3$ and 600 K, respectively.

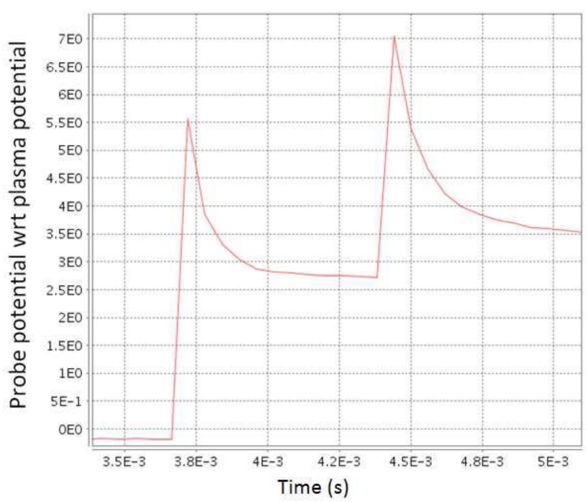

Fig. 7. Probe potential with respect to the plasma potential when 6- and 13-V steps are applied to the probe. Electron density and temperature are set to $10^{11}/\text{m}^3$ and 600 K, respectively.

have been performed for density ranging from $10^8/\text{m}^3$ to $5\times10^{12}/\text{m}^3$ for the two extreme values of electron temperature (600 and 6000 K). The simulations have been performed for an eclipse scenario (no photoelectron that can help mitigating S/C charging), which is the worst case. It can be seen from Fig. 8 that, for an applied bias voltage of 13 V, the maximum probe potential (with respect to the plasma potential) is ranging from 10.8 V down to 1.8 V depending on the plasma parameters. It is shown that the S/C charging effect is more severe at low electron temperature and high plasma density. Since the floating potential for electron temperature of 600 and 6000 K are -0.16 and -1.9 V, respectively, it is always possible to sweep in the electron saturation region with SLP on board PICASSO.

B. Electric Circuit Simulations

The electric circuit model shown in Fig. 9 has been used. The coupling between the probe and the plasma is modeled by

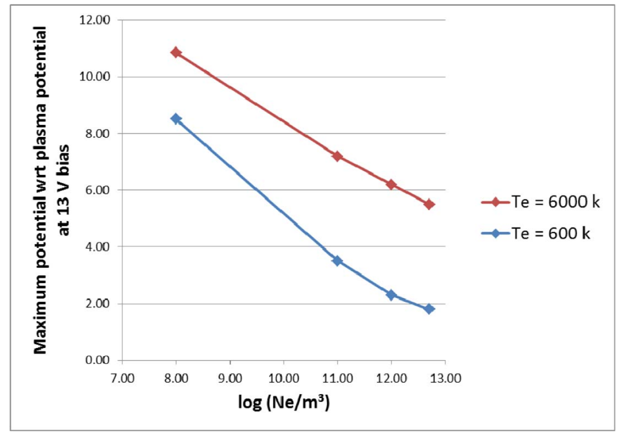

Fig. 8. Maximum probe potential with respect to the plasma potential at 13-V bias.

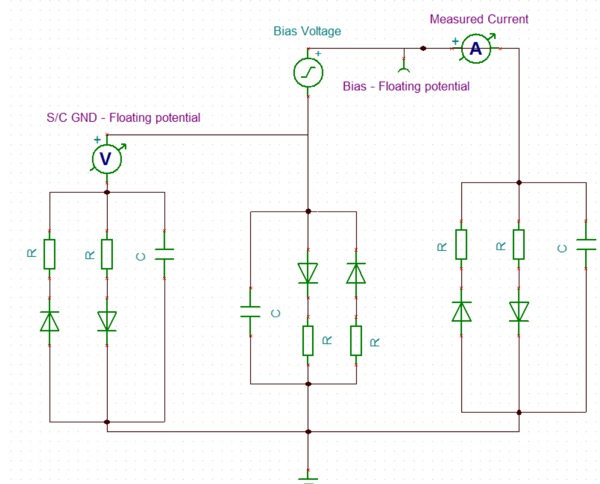

Fig. 9. Electric circuit model.

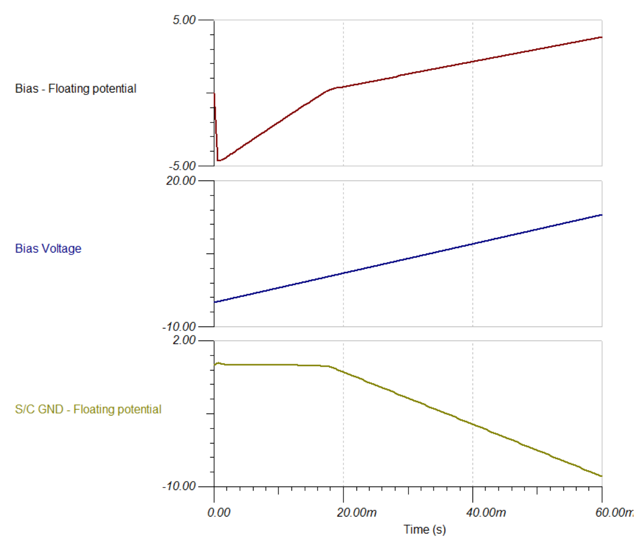

Fig. 10. From top to bottom: applied bias with respect to the floating potential, applied bias with respect to the S/C potential and S/C potential with respect to the floating potential.

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 modeled 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 modeled with an *R*–*C* circuit, similar 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 (before the measurement principle presented in this paper was implemented), where the electron density was about $2 \times 10^{11}/\mathrm{m}^3$ and the electron temperature was about 600 K.

It can be seen in Fig. 10 that, when the bias applied to the probe is swept from −5 to +13 V (with respect to the S/C potential), the S/C potential itself decreases down to −9.15 V (with respect to the floating potential). Then, the potential of the probe reaches only 3.85 V (with respect to the floating potential) instead of 13 V.

IV. Conclusion

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 S/C potential, is part of the payload of PICASSO, a triple unit CubeSat of dimensions 340.5 mm × 100 mm × 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 S/C, which leads to S/C 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. PIC and electrical circuit simulations have been performed to analyze and quantify the charging of the S/C. It is shown that, given the dimensions of the probe and the conducting area of the S/C, it is possible to sweep the probe in the three regions of interest (ion saturation, electron retardation, and electron saturation regions) even in the most unfavourable condition of the PICASSO mission (eclipse with high plasma density and low electron temperature).

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J. P. Lebreton, photograph and biography not available at the time of publication.