Abstract

One of the crucial measurements for characterizing any space weather event is absolute plasma density and plasma density fluctuations, both spatially and temporally. Among the various methods to perform in-situ plasma density measurements is a simple Langmuir probe. This poster discusses the various implementations of a Langmuir probe and why a Planar Ion Probe (PIP) is the easiest and best method to measure high cadence absolute ion density. We then present the design and performance of a PIP for the NASA LLITED dual CubeSat mission which is expected to be manifested for flight in late 2019. Performance data for the constructed PIP instruments is also presented. This includes noise analysis and calibration data, as well as refined instrument requirements. Due to its intended CubeSat platform, the designed instrument has extremely low size, weight, and power requirements. Thus, if needed, it can be deployed as a patch on multiple faces of a CubeSat, thereby reducing in-situ plasma density as well as enabling the study of the wake structure around the spacecraft.

Introduction

Coupling between Earth’s Ionosphere-Thermosphere (IT) regions has recently been observed to be more complex than previously expected. IT variations in the low-latitude dual-side manifest through two dominant phenomena: the Equatorial Ionization Anomaly (EIA) and the Equatorial Temperature and Wind Anomaly (ETWA), shown in figure 1 and 2 below. The EIA has been extensively observed and modeled, while the ETWA is relatively unknown.

Figure 1: Data from the CHAMP accelerometer (top panel; 10^-7 km/s^2), planar Langmuir probe (middle panel; 10^-11 m/s^2), GPS RO sounder (bottom panel; TOV), Cowley & grapes mark, the location of crests & trough, respectively. (adapted from Figures 1, 3 of Liu et al. [2010]).

The lack of data on the ETWA is due mainly to poor coverage of the region with properly instrumented spacecraft. Specifically, proper ETWA observation should nominally involve both neutral (thermosphere) and plasma (ionosphere) measurements. LLITED intends to be the first mission to collect coincident data pertinent to ET interactions at lower latitudes, expanding the knowledge base regarding the ETWA. The mission will collect neutral density, ion density, and total electron content profiles of the low-latitude IT region.

LLITED Mission

LLITED is a twinned 1U CubeSat mission and is expected to be launched in a 450 - 450 km orbit in 2019 or 2020. This will provide a wide global coverage of low-latitude ETWA regions. Observations of the low-latitude regions necessitate instruments only operate 25 - 45% of the orbital period. The dual satellites travel with 1/4 - 1/2 orbital separation, allowing for temporal observations of ETWA. LLITED satellite configurations after launcher separation (solar panels stowed) and during nominal science mission activities (solar panels deployed) depicted in figure 3.

LLITED directly addresses a key science goal from the IT region of the solar wind. During the heating period, the ETWA location moves southward and equatorward, and the ETWA peak intensity increases with applied potential (Fig 4a), and the current collected by planar probes remains essentially flat (Fig 4b).

Swapping 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. Thus, fixed bias probes are much preferred for small spacecraft such as a CubeSat. While probes fixed biased electron saturation region and protect themselves from noise, they do result in negatively charging the spacecraft.

Thus, for a CubeSat form-factor Langmuir probe, a fixed-bias probe in ion saturation region is a more effective arrangement. Using a flat plate probe has an additional benefit of being immune to variation in spacecraft charging potential, given the ion saturation region’s flat ion current response, as well as the benefit of not being a deployable.

Planar Ion Probe (PIP)

PIP is a flat-plate, fixed-bias Langmuir probe designed to remain in the ion saturation region, where negative voltage repels electrons and current collected is effectively due to ions only. Typically, Langmuir probes biased in ion saturation region measure thermal ion current, but at orbital velocities ion ram current is an order or magnitude larger than thermal current for planar geometry. Ion ram current is given by the expression

\[ I_{probe} = \frac{(q_i)}{(q)} V F A_{probe} \]

Where \( q_i \) is ion density, \( q \) is ion charge, \( V \) is spacecraft velocity, and \( A_{probe} \) is the ram cross section area. With the probe biased at the plasma density surface to the ram direction, and assumption of singly charged ions, one can directly derive absolute ion density from the current measurements.

PIP consists of two components: the Langmuir probe sensor and electronics processing board. Planar probe provides large-area ion collection, and guard strip around the probe provides infinite planar field geometry from the probe’s perspective. The probe guard is gold-plated to prevent corrosion and provide a uniform surface work function.

Swapping is an important concern for severely constrained CubeSat designs. PIP’s electronics board is very efficient and is approximately a fifth of a typical CubeSat stack PCB in area. PIP is provided with a 3V and 5V regulated supplies by the spacecraft power system.

PIP is designed for a 2 x 10^10 to 2 x 10^11 m^-3 dynamic range measurement. To accomplish this, dual 16-bit channels with gains of 1 and 100 cover the dynamic range. 10% minimum resolution, while high gain noise averages 19.8 counts, corresponding to ~6.25 x 10^3 m^-3 resolution – well within instrument requirements.

Summary and future work:

P-1 is an ultra low Swapping PIP with low noise instrument to measure in-situ absolute ion density. This poster presents an introduction to the LLITED mission and details the PIP mechanical and electrical design. The results presented here enumerate flight board characterization data. The flight electronics have completed design validation, testing, and performance validation. P-1 will be carried out, and integration with the LLITED CubeSats occurs in May 2019. The simple electronics and low Swapping make the P-1 excellent candidate for being applied as a patch to multitudes of spacecraft. Multiple identical instruments could be patched onto opposing spacecraft surface/footprint. CubeSat density measurements on spinning/tilting spacecraft. Lastly, for LLITED, the 16 oversampled data stream supports up to 150 Hz sampling. Our test results show that subsequent designs are easily capable of meeting 500 Hz sample rate without significantly deteriorating performance.

References