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Validation of double Langmuir probe in-orbit performance onboard a nano-satellite

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ABSTRACT

Many plasma measurement systems have been proposed and used onboard different satellites to characterize space plasma. Most of these systems employed the technique of Langmuir probes either using the single or double probes methods. Recent growth of lean satellites has positioned it on advantage to be used for space science missions using Langmuir probes because of its simplicity and convenience. However, single Langmuir probes are not appropriate to be used on lean satellites because of their limited conducting area which leads to spacecraft charging and drift of the instrument's electrical ground during measurement. Double Langmuir probes technique can overcome this limitation, as a measurement reference in relation to the spacecraft is not required. A double Langmuir probe measurement system was designed and developed at Kyushu Institute of Technology for HORYU-IV satellite, which is a 10 kg, 30 cm cubic class lean satellite launched into Low Earth Orbit on 17th February 2016. This paper presents the on-orbit performance and validation of the double Langmuir probe measurement using actual on-orbit measured data and computer simulations.

1. Introduction

Using Langmuir probe for plasma diagnosis is one of the oldest and proven techniques [1] which operate by immersing the conductive surface of an electrode into plasma and applying a controlled potential to the probe and then measure the current collected by the probe, varying the potential will cause the current to vary. The characteristic current-voltage (I—V) property can be used for estimating plasma parameters such as electron density, electron temperature, floating potential, plasma potential and electron energy distribution. This technique was first used by J.J. Thompson [1] to measure the potential distribution in gas discharge on ground. It was further developed by Langmuir and his collaborators [1,2]. Langmuir probe can be just a single electrode, double and also triple probes. Johnson and Malter in 1950 [2] described the double probes method to overcome the limitations of single probes by using a pair of probes of identical configurations (shape, size and material) connected by a variable potential source and electrically floating.

The main limitation of using single Langmuir probes for small satellites is the limited conducting area of the spacecraft, unlike the bigger spacecraft where the ratio of the sheath to the spacecraft size is negligible. Using double Langmuir probe (DLP) for plasma measurement is more reliable where reference ground is a concern, especially in the space environment where satellites with all its electronics are floating in plasma [2]. DLP is particularly advantageous over the single probe due to no ground issue, symmetrical current-voltage curve, no perturbation of bulk plasma, no magnetic field interference, and circuitry cannot be damaged due to high electron current flowing in the saturation region of single Langmuir probe. However, DLP is not free from limitations as it can accumulate high-energy electrons and consequently, electron temperature can be overestimated [3].

For more than five decades, Langmuir probes have been installed on satellites and sounding rockets to measure ionosphere's thermal plasma [4], which has contributed extensively to ionospheric studies and characterization of space plasma. Spacecrafts behave like a Langmuir probe in space plasmas [5], though their behavior is reverse of the Langmuir probe as their potential respond to the currents collected by its conducting areas from its environment instead of current as a response to potential in Langmuir probes. The sheath dimensions in relative to the size of the conductive parts of the spacecraft are very important in determining the current-voltage characteristics [6], it implies that small

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Nomenclature

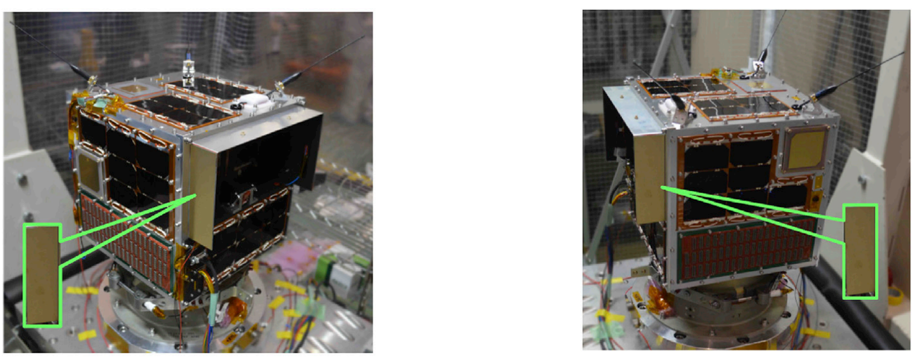
DLP	double Langmuir probe
KTe	average energy of electron in eV
e	unit electron charge
Iis	ion saturation current
Vin	bias voltage to positive probe
Vp	differential voltage between probes
K_B	Boltzmann constant
i	ion
DCDC	direct current to direct current converter
OBC	Onboard computer
EPS	Electrical power system

satellites are disadvantaged in using single Langmuir probe due to the issue of floating potential.

The recent growth of small satellites cannot be separated from the advancement of microelectromechanical systems (MEMS), which have direct applications in space technology. This has contributed to scaling down of satellite mission cost and development time. Consonantly, acceptance of higher mission risk and fragility has contributed to the ability of space technology to respond more to world events and satisfying more end users need. A group of experts under the International Academy of Astronautics (IAA) study group 4.18 [7] defined these types of satellites equivalent to small/micro/nano/pico satellite that utilizes untraditional risk-taking development approaches to achieve low-cost and fast-delivery as a *'lean satellite'*.

HORYU-II (7.1 kg, 30 cm cubic), a High Voltage Technology Demonstration Satellite developed and tested at Kyushu Institute of Technology was launched on May 18th, 2012 to an altitude of 680 km and 98.2° inclination [8]. The satellite was able to generate 300 V in Low Earth Orbit using high voltage solar array (HVSA) and detected many discharges while passing through the equator where plasma density is relatively higher than at the poles. It is therefore predicted that ambient plasma density has a very significant effect on solar cells discharge in space [8] but characterization of the discharges with respect to plasma condition was not possible, as the satellite did not have a plasma measurement mission onboard.

HORYU-IV satellite (10 kg, 30 cm cubic) was developed using the lean satellite project concept. The satellite was designed and manufactured in about two years at Kyushu Institute of Technology and it was launched as piggyback on February 17, 2016, by H-IIA rocket No. 30 from Tanegashima Space Centre in Japan [9]. The satellite main mission



a. HORYU-IV Satellite (-Y)　　**b.** HORYU-IV Satellite (+Y)

Fig. 1. a. HORYU-IV satellite (−Y) b. HORYU-IV satellite (+Y).

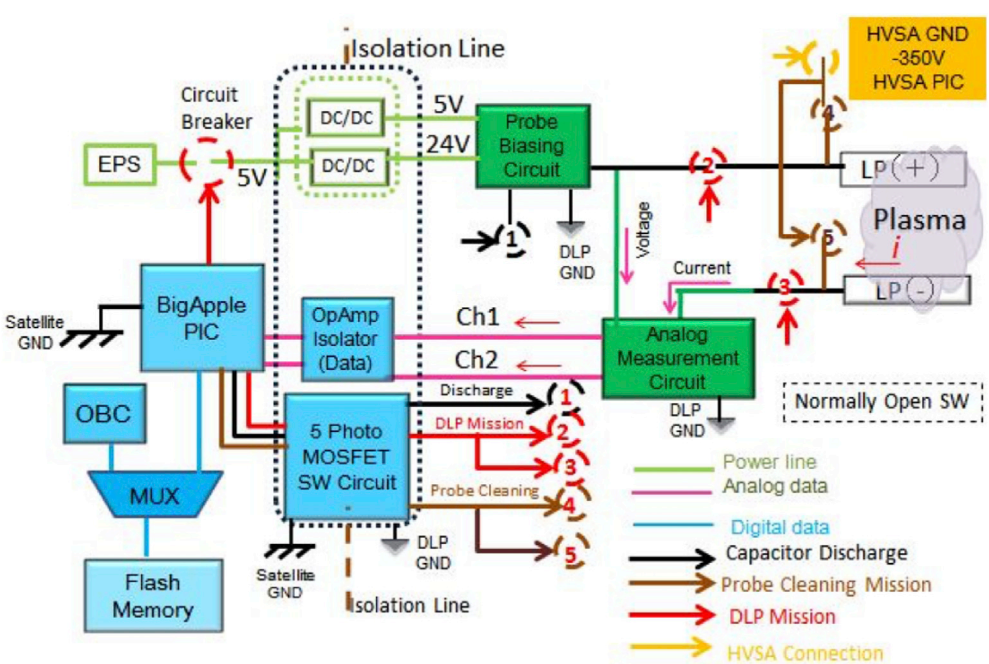


Fig. 2. Schematic of HORYU-IV DLP system.