

# Development of Low Cost Double Probe Plasma Measurement System for a Lean Satellite HORYU-IV

By Taiwo R. TEJUMOLA, Atomu TANAKA, Arifur KHAN, HORYU-IV Project Team and Mengu CHO

*Laboratory of Spacecraft Environment Interaction Engineering, Kyushu Institute of Technology, Kitakyushu, Japan*

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A lean satellite is equivalent to a small/micro/nano/pico satellite that utilizes untraditional risk-taking development approaches to achieve low-cost and fast-delivery. Lean satellites have demonstrated great ability to be used for the study of space plasma and Earth's ionosphere which has helped in the prediction of many astrophysical phenomena and forecasting of geophysical changes on ground. Several methods have been employed in the measurement of space plasma parameters over the years using the Langmuir Probe. These methods employed different techniques using single probes or double probes. Single probe requires a well-defined reference which is difficult in small spacecraft. Moreover, high current flow in the saturation mode may destroy the probe and on-board circuitry. A low cost double Langmuir probe made of gold with its measurement circuit has been designed and tested inside RF generated Argon plasma in the pressure of  $1.4 \times 10^{-2}$  Pa that confirms the electron density from  $10^{10}$  to  $10^{12}$   $m^{-3}$ . Important design considerations such as operability of the designed system in low earth orbit grade plasma, mitigation of probe contamination and sputtering of the electrode surface were analysed in the paper to ensure that the developed system can provide high fidelity plasma measurement data throughout the life span of HORYU-IV (Arc Event Generator and Investigator Satellite) which is a 13 kg, 40 cm cubic lean satellite under development at the Kyushu Institute of Technology.

**Key words:** Plasma, Double Langmuir Probe, Horyu-IV, Contamination, Lean Satellite

## Nomenclature

DLP	: double Langmuir probe
$kT_e$	: average energy of electron in eV
$e$	: unit electron charge
$I_{is}$	: ion saturation current
$V_{in}$	: bias voltage to positive probe
$V_p$	: differential voltage between probes
$k_B$	: Boltzmann constant

## Subscript

$I_s$	: ion saturation
$e$	: electron
$i$	: ion

## 1. Introduction

Langmuir probe is a plasma diagnosis technique which operates by immersing the conductive surface of an electrode (needle like, flat or spherical) into plasma to measure the current-voltage ( $I-V$ ) characteristics that can be used for estimating the yielding density and energy of the ions/electrons. This technique is widely used and reliable for the measurement of plasma parameters which is applicable in the diagnosis of analytical spectroscopy, plasma processing, Plasma-enhanced chemical vapor deposition (PECVD), new material synthesis, plasma thruster, even for ionospheric studies and space plasma characterization.

small/micro/nano/pico satellite that utilizes untraditional risk-taking development approaches to achieve low-cost and fast-delivery.

The lean satellite concept allows multiple satellites development instead of a single satellite, as well as improved

These plasma parameters can be measured by using both single or multiple Langmuir Probes. Johnson and Malter in 1950<sup>1)</sup> described the double probes method to overcome the limitations of single probe method by using a pair of probes of identical configuration connected by a variable potential source.

Double Langmuir Probe (DLP) measurement systems are more reliable where reference ground is a critical issue, especially, in the space environment, where satellites with all its components are floating in plasma.<sup>2)</sup> DLP is particularly advantageous over the single probe owing 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. However, DLP is not free from limitation. Sometimes, it accumulates high-energy electrons and consequently, electron temperature is overestimated.<sup>3)</sup>

Recent advancement in Microelectromechanical systems (MEMS) applicable for small-satellites missions is becoming more popular due to low cost, short development time and the use of commercial off-the-shelf components (COTS). Concept of "lean satellite" has been recently proposed by a group of experts who studied on definition and requirements of small satellites under the International Academy of Astronautics (IAA) study group 4.18.<sup>4)</sup> A lean satellite is equivalent to a

test bed for new flight hardware. This breakthrough has contributed to the use of lean satellites for the characterization of ionospheric plasma as many small satellites use Langmuir probes (single and multiple) with associated onboard circuitry to measure the plasma parameters and its temporal variation.

<sup>5,6,7)</sup> However, the circuitry demand is complex and the measurement system can also contribute significantly to satellite mass which is very limited in lean satellites.

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 18<sup>th</sup> 2012 to an altitude of 680 km and 98.2° inclination.<sup>8)</sup> The satellite was able to generate 300 V in Low Earth Orbit using the 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 very significant effect on solar cells discharge in space but characterisation of the discharges with respect to plasma condition was not possible as the satellite does not have a plasma measurement mission onboard.

HORYU-IV (12 kg, 40 cm Cubic), an Arc Event Generator and Investigator satellite as shown in Figure 1 is under development at Kyushu Institute of Technology and shall be launched to an orbit of 575 km with an inclination of 31° in February 2016 via HIIA rocket made by Japan. This satellite shall be equipped with HVSA to generate 300 V in Low Earth Orbit and use this high voltage to perform discharge experiment and capture the discharge waveform image by an arc vision camera onboard. Plasma measurement mission is significant for HORYU-IV satellite to estimate the role of plasma parameters before and just after the discharge to enable proper characterization of solar cells discharges with reference to different plasma conditions. In order to overcome the complications of single Langmuir Probe and related massive circuitry, a low cost and lightweight DLP system has been designed. In-situ contamination of electrodes surface in space environment limits the operational life span as well as data reliability of Langmuir probe missions,<sup>2, 3, 5, 6)</sup> there are several proposals to overcome this limitation.<sup>2, 3, 5)</sup> Since HORYU-IV satellite would be able to generate high voltage up to 300 V, it has been planned to clean (in situ) the probes by biasing the probe at -300 V to allow heavy ions to clean the surface (ion bombardment/sputtering method). This paper explains the performance of developed DLP system with measurement circuit in plasma as well as other design specifications.

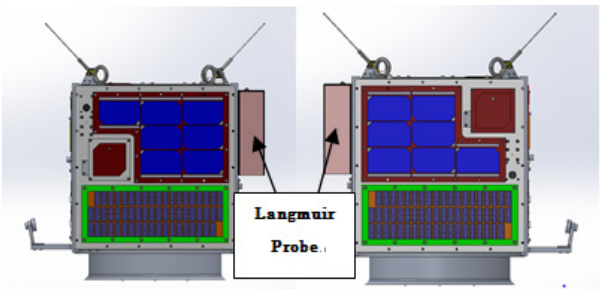


Fig. 1. +Y plane (Left) and -Y plane (Right) of HORYU-IV satellite showing the flat Langmuir probes (DLP) on the hood.

## 2. Principle of Double Langmuir Probe

The Double Langmuir Probe (DLP) system consist of two symmetric shape electrodes which are of identical configuration and material that can sustain high heat loads from plasma and does not significantly erode by sputtering. They are placed apart from each other at a distance that is far enough that the plasma sheaths of the individual probes did not overlap but not so far away to have different plasma regions.

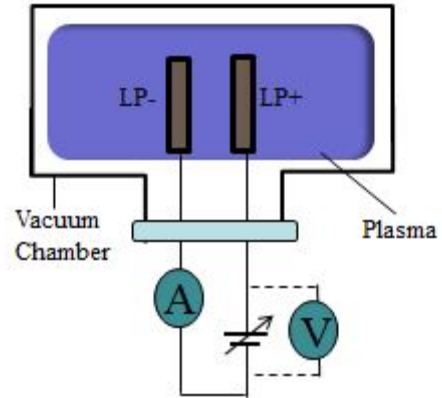


Fig. 2. Schematic of principle of double Langmuir Probe.

Figure 2 shows a Positive probe (LP+, biased positively) connected to a variable voltage source, whereas reference probe (LP-) was connected to the voltage source reference through a resistor to measure the current passing from LP+ to LP- through the plasma. When the differential voltage between the two probes ( $V_p$ ) and corresponding current ( $I$ ) are plotted, a symmetric curve is obtained if the plasma obeys the Maxwellian energy distribution. From the current-voltage ( $I$ - $V$ ) plot, electron temperature  $T_e$  can be measured by the Eq. (1)<sup>2)</sup>.

$$\left( \frac{dI}{dV_p} \right)_{V_p=0} = \frac{eI_{is}}{2k_B T_e} \quad (1)$$

Where,  $T_e$ ,  $k_B$  and  $I_{is}$  are the average energy of the electron, Boltzmann constant and ion saturation current respectively. Since the  $I$ - $V$  curve is symmetric, Eq. (1) can be re-written as Eq. (2), when voltage scanning is from negative maximum to positive maximum and corresponding graph is shown in Figure 3.

$$\frac{k_B T_e}{e} = \frac{1}{2 \left( \frac{dI}{dV_p} \right)_{V_p=0} - \frac{1}{2} \left( \frac{dI_{i+}}{dV_p} + \frac{dI_{i-}}{dV_p} \right)_{V_p=sat}} * \left( \frac{2I_{i+} + I_{i-}}{I_{i+} + I_{i-}} \right)_{V_p} \quad (2)$$

In Eq. (2),  $I_{i+}$  and  $I_{i-}$  represent the positive and negative ion saturation current where slope of the positive and negative saturation current cut on the current direction ( $y$ -axis).

According to the proposed circuitry, only positive voltage is applied to the LP+, therefore, Eq. (2) can be further simplified to Eq.(3).

$$\frac{k_B T_e}{e} = \frac{I_{is}}{2 \left( \frac{dI}{dV_p} \right)_{V_p=0} - \left( \frac{dI_{i+}}{dV} \right)_{V_p=sat}} \quad (3)$$

If  $T_e$  is known,  $n_e$  can be confirmed from Eq.(4), as shown below.<sup>2)</sup>

$$I_{i+} = 0.61 n_e e A \sqrt{\frac{k_B T_e}{m_i}} \quad (4)$$

Where, A is the surface area of the probe and  $m_i$  is the mass of the ion (Argon ion, in case of ground plasma). However, at high voltage the sheath is expanded, the saturation current shows the rising behavior rather than flat nature.

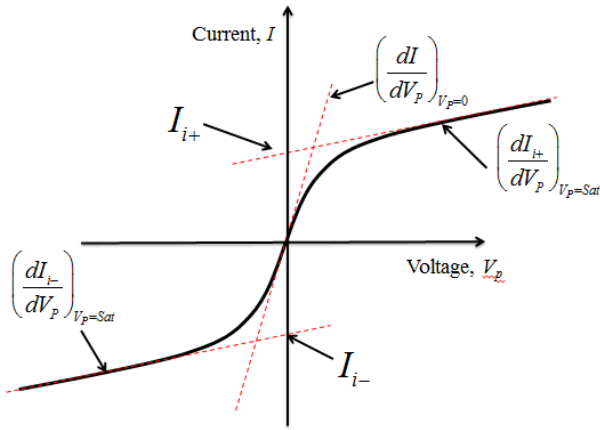


Fig. 3. Current-Voltage characteristic of double Langmuir probe.

### 3. Circuitry of Double Langmuir Probe

The DLP circuitry consists of the probe biasing circuit and the voltage measurement circuit. The probe biasing circuit consists of two sequences depicted as 1 and 2 in Figure 4a. The first sequence consists of a designed RC circuit (1 MΩ, 10 μF) to bias the LP+ from 0V to 26 V. The 10μF capacitor in the RC circuit is charge by a 26 V supply from a DC/DC converter run by 5 V (simulating satellite bus). During charging phase, the LP+ connected to the RC at point where V1 is measured

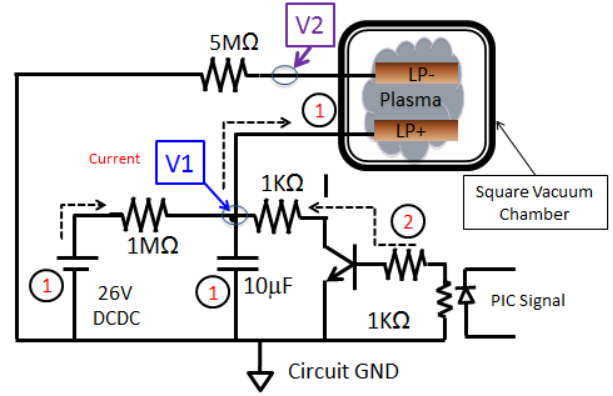


Fig. 4a. DLP Biasing RC circuit and reset switch for capacitor.

The symmetric probes LP+ and LP- were connected through cables fed to the probe biasing circuit placed outside the chamber on a test bench. The schematic of the probe biasing circuit is as shown in the Figure 4a and Figure 4b.

During the LP+ bias phase, V2 is also measured to record the current passing through the 5 MΩ resistor. The second phase represents the capacitor discharging phase, after voltage saturation, capacitor needs to be reset to 0V for the next run by discharging it through a transistor controlled by a signal on a Photo MosFet from a microcontroller. The voltage difference (V1-V2) between probes LP+ and LP- is represented as  $V_p$

While ion current passing through the plasma to the LP- probe to the reference ground, is measured by voltage drop (V2) across the 5 MΩ resistor as shown in Figure 4b.

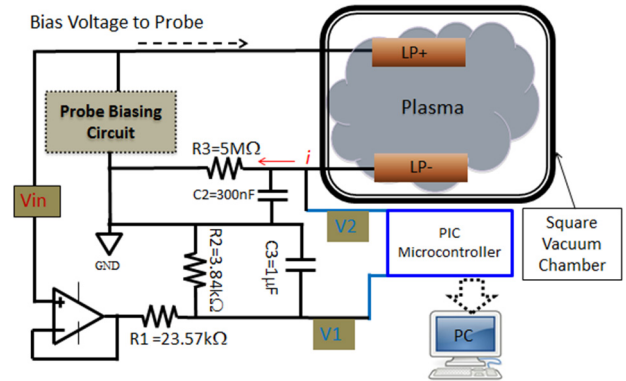


Fig. 4b. Schematic of full plasma measurement circuitry (PMC).

Figure 4b shows the full circuitry of current and voltage measurement, LP+ voltage ( $V_{in}$ ) was fed to an OpAmp, which act as a voltage follower.  $V_{in}$  was down converted by two resistors (R1 and R2) to ensure a voltage level appropriate for PIC microcontroller and noise was reduced by capacitor (C3). The ion current passing through the plasma to the LP- is measured as voltage drop (V2) across the 5 MΩ resistor. V1 and V2 were fed into the microcontroller through A/D converter ports and recorded by personal computer. The

values of  $V_1$  and  $V_2$  can be used to compute the I-V curve of the Langmuir probes as follows.

$$V_{in} = V_1 * \frac{R_2}{R_1 + R_2} \quad (5)$$

$$i = \frac{V_2}{R_3} \quad (6)$$

#### 4. Experiments

Experiments were performed to confirm the operation of the proposed DLP system and to validate its accuracy. The experiments used a square plasma chamber of dimension 115x100x75 cm, located at the Laboratory for Spacecraft Environment Interaction Engineering (LaSEINE) of Kyushu of Kyushu Institute of Technology. The Plasma was made by an RF generator (13.56 MHz, model: T857-2) combined with a matching box (L/CON300PF and C-102Y). Argon gas was fed at a flow rate of 10sccm controlled by a flow-meter (STEC Mass flow system, Model: PAC-3HS) and the power level was set below 20W. During the experiments, the gas pressure inside the chamber was maintained at  $2.2 \times 10^{-2}$  Pa. The chamber was evacuated by a cryogenic pump (Ulvac Cryogenics, Model: CRYO-U 16) backed by two mechanical pumps connected in series that confirmed the ultimate vacuum level of  $1.3 \times 10^{-2}$  Pa.

The first experiment was to validate the operation of a pair of flat Langmuir probes as a double Langmuir probe system; the set-up is shown in Figure 5. The biased probe is marked as LP+ and the reference probe is marked as LP-. The bias voltage was applied by a source meter (Keithley 2400). Ion current received by reference probe was measured by the voltage drop across a 5 MΩ resistor. Both LP+ and LP- voltages were measured by two digital multi-meters (Keithley 2000) separately controlled by LabVIEW program.

Figure 6 shows the experimental result using a voltage source meter at four different voltage ranges to bias the probes and measured data was recorded by digital multi-meter (DMM) controlled by computer. The pattern of I-V curves at different voltage ranges (-100V to +100V, -50V to +50V, -30V to +30V, and 0V to +30V) proved the authenticity of the DLP system. However, at high positive and negative voltage the current is rising. This is due to the rising of the sheath thickness.

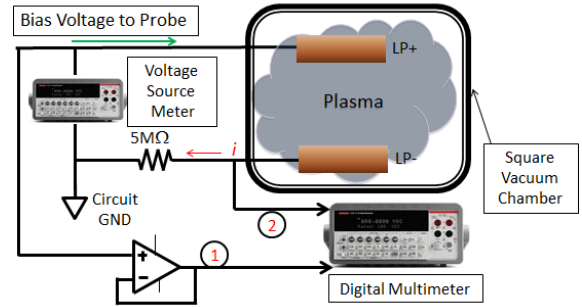


Fig. 5. Experimental setup to validate DLP operation.

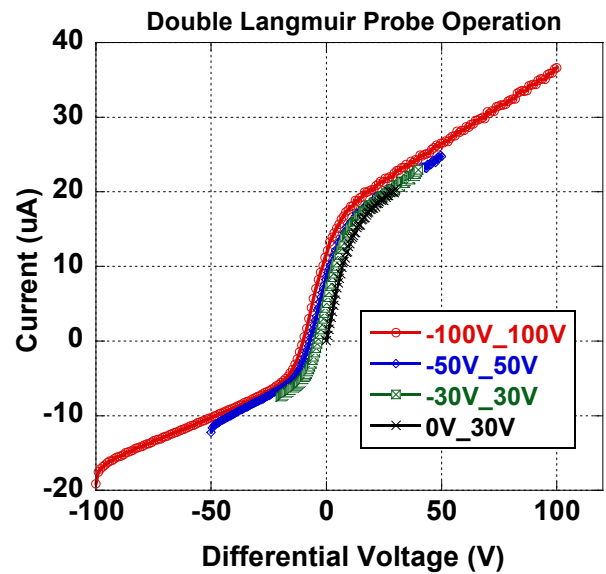


Fig. 6. Double Langmuir Probe (DLP) I-V curve measured by source meter at four different voltage ranges.

The second experiment is to validate the accuracy of the DLP measurement using single Langmuir probes. Two sets of single Langmuir probes made of gold were located at 70 cm apart in the square chamber. The two square plates, 4cm x14cm each, made of gold were fixed on the +Y and -Y axis of HORYU-IV satellite structural thermal model (STM). All circuitry were placed outside the plasma chamber and connected to all probes inside the chamber through the vacuum chamber feedthroughs. Figure 7 shows the locations of the probes viewed from the top of the chamber. The plasma source is located at the ceiling of the chamber. The distance from the plasma source exit to each probe is the following; SLP1 70 cm, SLP2 30 cm, DLP 40 cm (symmetrical). It was ensured that the probes were setup to be far away from the chamber wall, at least 20 cm apart, to prevent the sheath of the probes from interacting with the wall of the chamber. We used a source meter (Keithley 2400) to bias and measure the current of the spherical Langmuir probes, SLP1 and SLP2. PMC shown in Figure 4a and 4b were attached to DLP and the data was collected by PC.

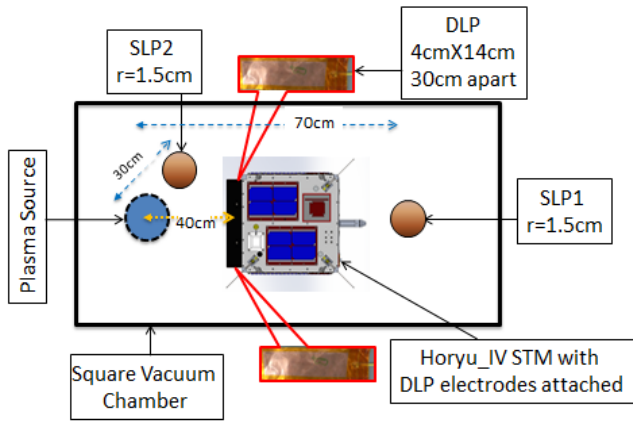


Fig. 7. Plan view of vacuum chamber showing probe arrangements inside to confirm plasma distribution.

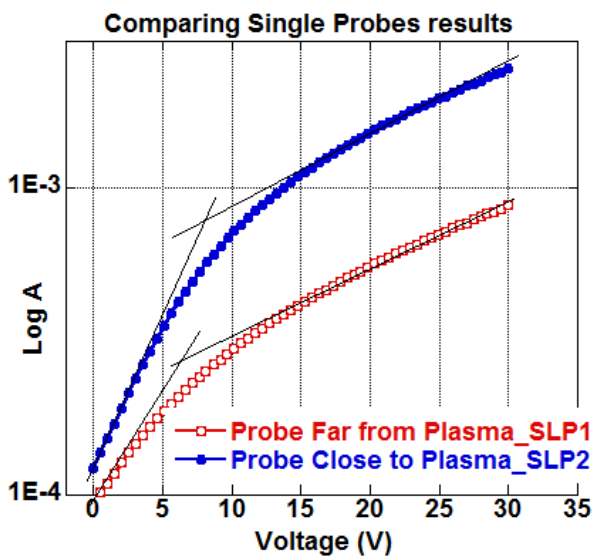


Fig. 8. I-V Curve for 2 different Single Langmuir Probes located at different points in the vacuum chamber to demonstrate the distribution of Plasma inside the vacuum chamber.

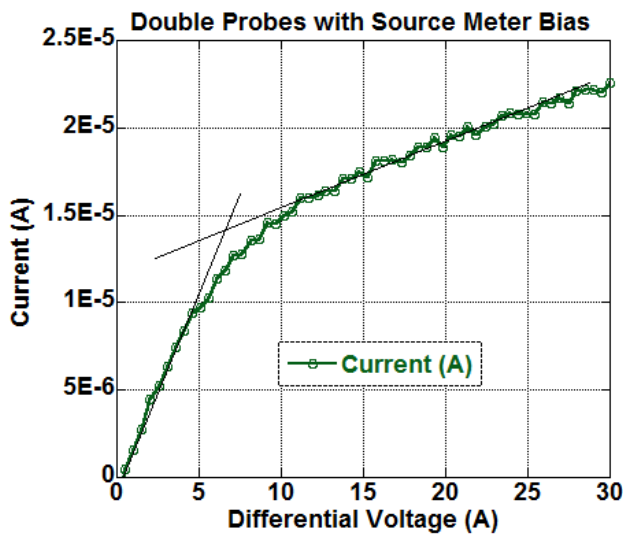


Fig. 9. I-V Curve for double Single Langmuir Probe to demonstrate even distribution of Plasma inside the vacuum chamber.

Figure 8 and Figure 9 give the representative I-V curve for the two cases respectively and Table 1 give the computed plasma parameters. The computed plasma temperature  $T_e$ , plasma density  $n_e$  and Debye length  $\lambda_D$  of the plasma showed a great compliance for all the probes as shown in Table 2.

Table 1. Computed values for plasma parameters measured by three different methods.

Probe Configuration	$T_e$ (eV)	$n_e$ ( $m^{-3}$ )	$\lambda_D$ (cm)
SLP1	5.7	$1.5 \times 10^{12}$	1.5
SLP2	4.0	$5.1 \times 10^{12}$	0.65
DLP_H4	3.1	$8.7 \times 10^{12}$	0.44

Validation of the experimental I-V plots for the single Langmuir probe was done using the theory of Langmuir probe by Laframboise in 1960s.<sup>16)</sup> Table 5c of Reference 16) was used. The table provided theoretical factors of electron saturation current ( $I_{es}$ ) values for different values of the ratio of  $e\phi_p/kT$  against the ratio  $R_p/\lambda_D$  where  $e$  is fundamental charge,  $\phi_p$  is the electrical potential of the probe with respect to the plasma,  $kT$  is the plasma temperature,  $R_p$  is the radius of the spherical probe (1.5 cm) and  $\lambda_D$  is the Debye length.

This theoretical analysis was applied to the I-V curve of SLP1 and SLP2 of Figure 8 and Figure 10 plots theoretical numbers derived from Table 5c along with the experimental result. We plot the case of  $R_p/\lambda_D=1$  for SLP1. We plot the case of  $R_p/\lambda_D=2$  for SLP2 although the experimental result gives  $R_p/\lambda_D=2.3$ . The theory and experiment agree each other within a factor of 1.5, demonstrating the validity of SLP.

Comparing DLP and SLP, the plasma density derived by DLP is more than those measured by SLP1 and SLP2. As DLP was closer to the plasma source, it is understandable that DLP density is higher than SLP1 density. DLP density, however, is still larger than SLP2. Considering the discrepancy between the theory and the experiment of SLP, the density at SLP1 location is between  $0.75 \times 10^{11} m^{-3}$  and  $2.2 \times 10^{12} m^{-3}$ . The density at SLP2 is between  $2.5 \times 10^{12} m^{-3}$  and  $7.5 \times 10^{12} m^{-3}$ . Assuming that DLP value is the middle between the SLP1 and SPL2 values, it is between  $1.5 \times 10^{12} m^{-3}$  and  $5 \times 10^{12} m^{-3}$ . The measured DLP value is  $8.7 \times 10^{12} m^{-3}$ . Overall, DLP can overestimate the plasma density by a factor of 5 at most. We still need to carry out further laboratory tests to calibrate DLP and improve its accuracy.

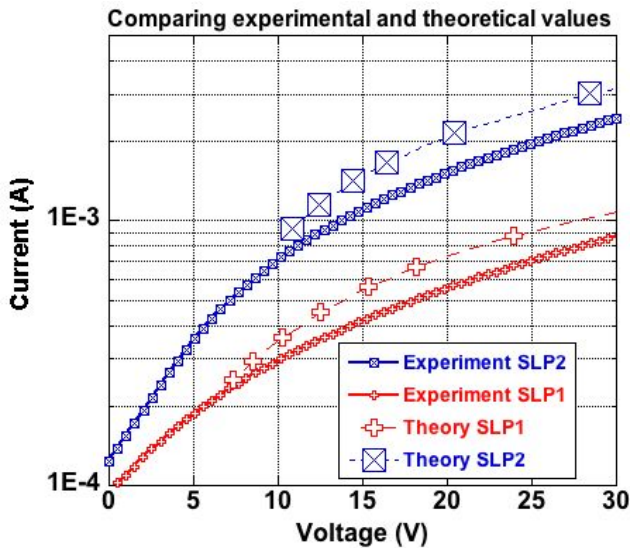


Fig. 10. Comparison between experimental I-V curve and theoretical I-V curve for single Langmuir probe.

The third experiment was to compare the operation of the designed DLP system connected to the Engineering Model electronics with a standard single Langmuir Probe measurement. Figure 11 shows the BigApple electronics board where four mission electronics were implemented including the DLP electronics.

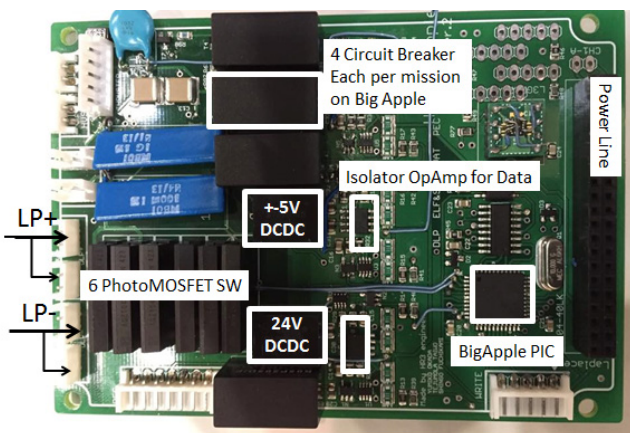


Fig. 11. EM Ver.2 of BigApple circuitry board showing DLP Circuit.

The DLP on HORYU-IV STM were made up of two flat probes made of gold plated PCB attached on the +Y and -Y axis of the satellite as shown in Figure 1, these probes were biased with the probe biasing circuit (RC circuit consisting of a 1MΩ resistor and 10μF capacitor that was able to bias the LP+ probe up to 26 V). The voltage and current data were collected through the designed analog measurement circuit by the BigApple PIC microprocessor shown in Figure 11. The data was then transferred from the PIC microprocessor to a PC. During the experiment, the circuit board was placed outside the chamber. The single Langmuir probe was biased with the

voltage source meter and voltage and current data was also collected with the source meter.

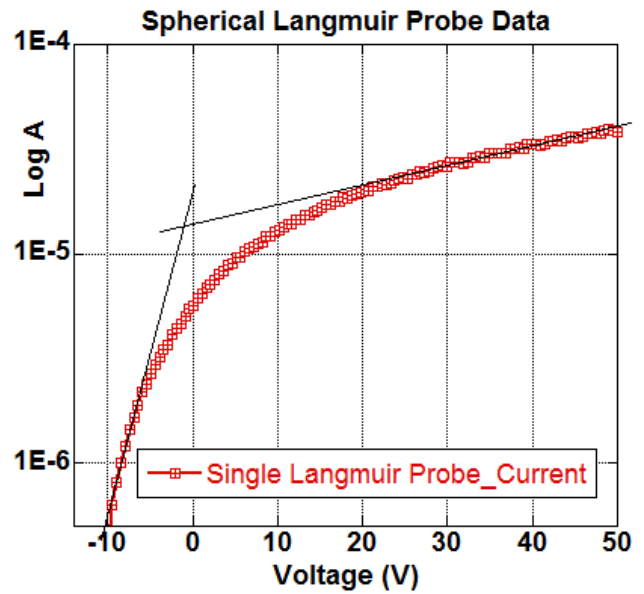


Fig. 12. I-V curve of single Langmuir probe measured by Source meter.

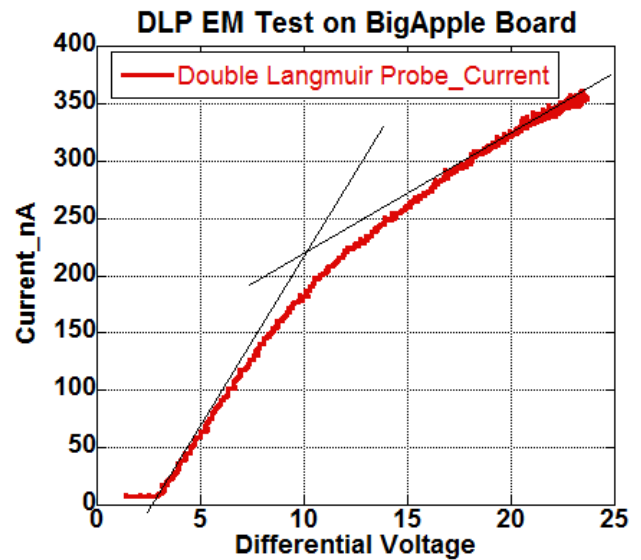


Fig. 13. I-V curve of double Langmuir probe measured by with the Plasma measurement circuit.

From the I-V curve shown in Figure 12 and Figure 13, plasma parameters (electron temperature ( $T_e$ ), electron density ( $n_e$ ), and Debye length ( $\lambda_D$ )) were calculated using Eq. (3) and Eq. (4) and shown in Table 2. Result obtained from single Langmuir probe (SLP) and DLP as shown shows that the developed DLP system including electronics is able to measure the plasma parameters.

Table 2. Computed values for plasma parameters for single Langmuir probe and double Langmuir probes.

Langmuir Probe Type	$T_e$ (eV)	$n_e$ ( $m^{-3}$ )	$\lambda_D$ (cm)
Single Langmuir Probe	2.8	$1.1 \times 10^{11}$	3.8
Double Langmuir Probe	4.3	$1.3 \times 10^{11}$	4.3

### 6. Design Specifications

Space environment is quite different from what is experienced on earth. Hence, there is need for important design considerations such as operability of the designed plasma measurement system in low earth orbit grade plasma environment, mitigation of on-orbit probes contamination due to ion deposition, rate of sputtering of gold coating on electrodes to confirm the operability of the DLP mission for a 2 years nominal period. On-orbit probe contamination effect is planned to be overcome through ion bombardment by using high voltage generated by HORYU-IV satellite. Data from International Reference Ionosphere (IRI) computation shows that for one solar cycle, the electron temperature is in the range of  $0.07\text{eV} \leq T_e \leq 0.24\text{ eV}$  and the electron density can be between  $8 \times 10^9\text{ m}^{-3} \leq n_e \leq 8 \times 10^{11}\text{ m}^{-3}$ . This situation was tried to simulate in the laboratory, it is very difficult to make tenuous plasma. We covered the plasma source with an aluminum box having an opening of  $\phi = 10\text{ mm}$  and keeping the probes away as much as possible from the plasma source. The plasma power was set to as low as 10W, possible lowest value with a gas flow rate of 10 sccm. The two square plates, 4 cm by 14cm each, made of gold were fixed on the +Y and -Y axis of HORYU-IV STM and was biased using the EM circuit board shown in Figure 11. All circuitry were placed outside the plasma chamber and connected to all probes inside the chamber through the vacuum chamber feedthroughs.

After the plasma become stable, data was collected and the I-V curve was drawn as shown in Figure 14. From the best fitting of the curve, electron temperature and density was calculated and found as 1.3 eV and  $2.7 \times 10^{10}\text{ m}^{-3}$  respectively. In Figure 14, the maximum resolution of digitization is already seen. Probably, we can retrieve a meaningful I-V curve up to 10 nA of the saturation current. With 10 nA, assuming the electron temperature of 0.07 eV, the lowest plasma density we can measure in orbit is  $2.9 \times 10^{10}\text{ m}^{-3}$ . This value is higher than the requirement,  $8 \times 10^9\text{ m}^{-3}$ , but it is good enough considering the nature of lean satellite mission.

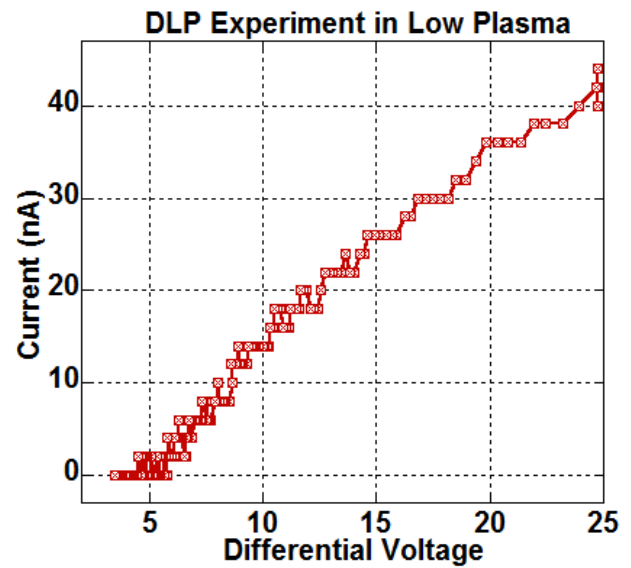


Fig. 14. Plasma parameter measured with double flat probe at low plasma condition using the DLP and PMC.

The double Langmuir probe mission for HORYU-IV satellite is planned to be able to measure plasma parameter throughout the nominal life span of the satellite. However, continual exposure of probe electrodes to plasma environment makes the surface dirty due to heavy ion contaminations and hence introduced errors in the the estimation of electron temperature measurement.

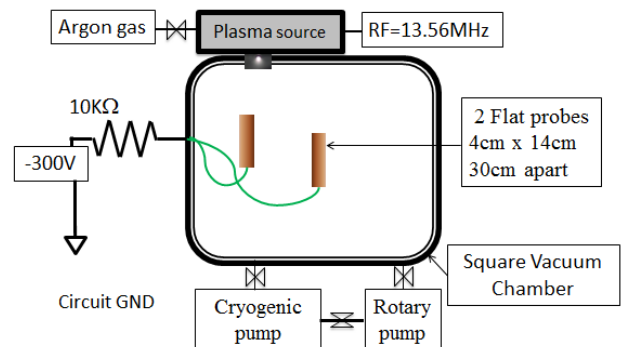


Fig. 15. Experimental setup for Laboratory demonstration of Probe contamination cleaning using -300V.

In the laboratory, the effectiveness of cleaning by high voltage has also been investigated. Figure 15 shows the schematic of the probe cleaning method through ion bombardment by applying negative 300 V for 5 minutes to the probes kept inside the chamber where the plasma density was in the order  $10^{11}\text{ m}^{-3}$ . The I-V curves taken before (blue line) and after (red line) the cleaning is shown in Figure 16 From the I-V curve it is clear that -300 V bias effectively clean the probe surface.

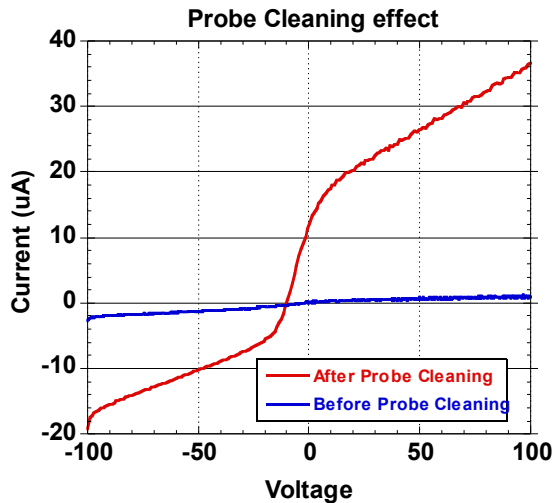


Fig. 16. I-V curve demonstrating the effect of Probe cleaning using -300V for 5 minutes.

Exposure of electrodes to heavy ions causes the surface of the electrode to sputter after long time operation; erosion of gold from the surface of the Langmuir probes is envisaged due to ion bombardment especially during application of -300V on the probe surface. An important design consideration is to design the appropriate gold thickness that can be sustained throughout the operation life span of HORYU-IV satellite. Combining ion current crossing over the sheath boundary and sputtering rate relationship as shown in Eq. (7) and Eq. (8).

$$J_{c-L} = en_i * \sqrt{\frac{kT_e}{m_i}} \quad (7)$$

$J_{c-L}$  is ion current crossing over the sheath boundary,  $e$  is unit electronic charge,  $n_i$  is the ion number density,  $k$  is Boltzmann constant,  $T_e$  is the average energy of electron and  $m_i$  is the mass of ion.

The sputtering rate

$$\dot{Z} = \frac{M}{\rho N_A e} * S * J_{c-L} \quad (8)$$

Where  $\dot{Z}$  is the sputtering rate measured in meter per seconds,  $M$  is the molecular mass,  $S$  is the sputtering yield for the material,  $\rho$  is the density,  $e$  is unit electronic charge and  $N_A$  is Avogadro number.

From Eq.(7), and using International Reference Ionosphere (IRI) data applicable for HORYU-IV orbit, where  $T_e$  is about 0.1eV (considering upper limit for the ion density of  $1 \times 10^{12} \text{ m}^{-3}$ ) and using other constants values, the maximum current density is found to be about  $1.2 \times 10^{-4} \text{ Am}^{-2}$ .

From Eq. (8), using the value of maximum current density of  $1.2 \times 10^{-4} \text{ Am}^{-2}$  computed from Eq.(7), assuming a sputtering yield of 1.6 atoms per ion, and considering density and molecular weight of gold material. The sputtering rate was computed, as  $2 \times 10^{-14} \text{ m/s}$ . hence about  $0.6.4 \text{ }\mu\text{m}$  thickness of

the gold would be sputtered in 1 year and about  $1.9 \text{ }\mu\text{m}$  thickness would be sputtered away in 3 years if we continuously bias the probes. However, the probes will not be bias continuously. Therefore, we chose  $1 \mu\text{m}$  thickness for gold coating of HORYU-IV DLP.

## 7. Conclusion and Future Plan

In order to measure in-situ plasma parameter at the altitude of 575 km and  $31^\circ$  inclinations, a double Langmuir probe (DLP) with associated circuitry (Plasma measurement circuitry, PMC) has been developed as a subsystem of HORYU-IV satellite. In laboratory tests, it was confirmed that DLP and PMC system could measure the plasma electron density in the range of  $10^{10}$  to  $10^{12} \text{ m}^{-3}$ . Important design considerations such as operability of the plasma measurement system in LEO grade plasma, electrode contamination in space and sputtering of electrode surface in space have been considered during the design and verified for the system. After successful integration of the Flight Model, HORYU-IV flight model is now complete. HORYU-IV satellite will be launched in February 2016 by HIIA rocket.

While we wait for the launch, we need to carry out laboratory tests further to calibrate the DLP measurement data and improve its accuracy using a flight spare.

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