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Langmuir probe experiments on Korean satellites

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ABSTRACT

We report in this paper the test results of the Langmuir Probes (LPs) that have been used on several Korean low earth orbit (LEO) satellites since 1999. The probes were designed to measure the electrons in the density range of $\sim 10^4$ to $\sim 10^6/\text{cm}^3$ and temperatures less than $\sim 10^4$ K, which are the typical characteristics of the upper ionosphere. Careful considerations were given to the probe design to reduce many error sources. For example, a 10 Hz fast voltage sweep was applied to the probe to minimize measurement errors caused by probe contaminations. An electron temperature probe was installed in addition to the LP on the KOMPSAT-1, and the electron temperatures measured simultaneously and independently by the two instruments were compared. The results showed good agreement, which confirms the validity of the LP data obtained from these Korean satellites.

1. Introduction

The ionosphere, located in the altitude range of 80 km–1000 km and above, is in a plasma state with neutral particles ionized by solar extreme ultraviolet (EUV) and X-ray radiations. The plasma characteristics of the ionosphere have been obtained by direct as well as indirect methods. For example, the radio sounding method utilizes the propagation property of radio waves that are reflected from the ionosphere when the wave frequency is lower than the local plasma frequency [1]. Incoherent scatter radars provide additional information such as electron and ion temperatures [2]. The ionosphere can also be directly measured using various instruments installed on rockets and satellites [3–5]. A notable example is the Langmuir probe (LP). The use of an LP in space was first made by Reifman and Dow [6] when they installed it on a reformed V-2 rocket to obtain the ionospheric electron density and temperature. The LP's simple operational principle, together with its capability to probe local structures, made it widely used from the early days of space experiments, such as those installed on the Explorer-17, -22, and -23 [7], to recent missions such as DEMETER [8]. The directly and indirectly observed data have been used to verify the mathematical models [9,10].

There are many factors to be considered when the LP is used in space since various error sources exist, which are discussed below: it is generally said that electron temperature and density have 5% and 10% errors, respectively, in good measurements [11]. First, it should be noted that the satellite body itself is an electrical probe in space. As the currents from the LP are fed to the satellite, the satellite potential, with respect to ambient plasma, changes significantly unless the conducting area of the satellite is large compared to that of the probe. The satellite area should be at least several hundred times larger than that of the probe. Furthermore, the induced electrical field along the probe, due to the motion of the spacecraft across the geomagnetic field, must be small. For a typical LEO satellite, the ram velocity is ~7 km/s, which yields, with 0.5 G geomagnetic field, ~350 mV/m. Then, for a probe of 100 mm length, the potential difference along the probe is 35 mV, which is small compared to the potential of the electron-retarding region.

In addition, the LP has to be located outside the plasma sheath as well as the wake generated by the main body satellite. Since the ram velocity of the satellite is greater than the typical ion thermal velocity, but smaller than the electron thermal velocity, charge neutrality is not maintained in the wake region. The probe must be made of high purity material so that it has a uniform work function. Otherwise, non-uniform voltage appears on the surface of the probe, causing serious errors in electron temperature measurements, especially in low temperature regions such as the E layer of the ionosphere [12].

Another serious error source encountered in space experiments is the contamination of the probe surface produced by moisture in air when the probe is being manufactured on the ground. It is known that even recent missions, such as CHAMP and DEMETER, suffered such contamination effects and reliable plasma

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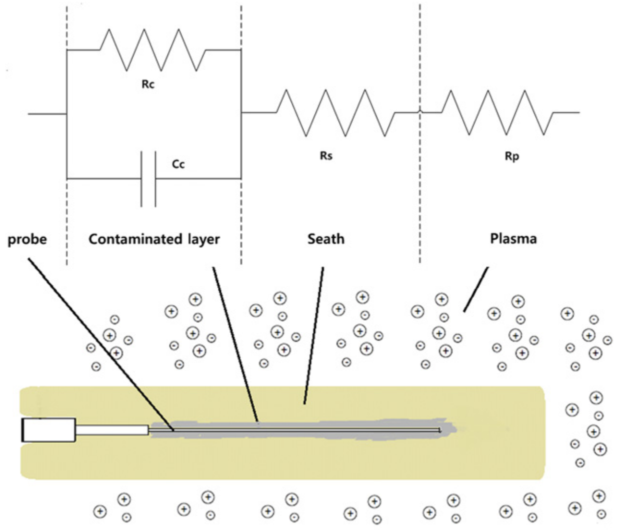

Fig. 1. Contamination layer on the probe surface, shown with a sheath of plasma (bottom) and its equivalent circuit (top).

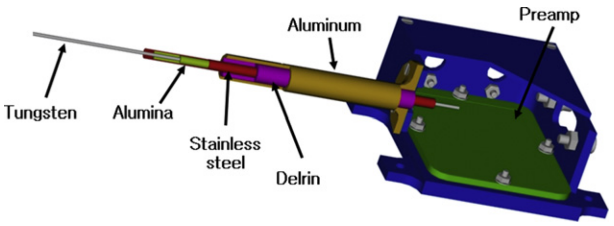

Fig. 2. Mechanical structure of a typical LP installed on Korean LEO satellites.

characteristics were not obtained from the Langmuir probe experiments on these satellites [13]. There have been many suggestions to reduce the contamination effect: adoption of redundant LP sensors to detect the presence of surface contamination, heating of probe tips using internal filaments, use of ionospheric electrons to bombard the probe surfaces, and even using glass-sealed LPs which are to be exposed in space by breaking the glass tubes [14].

The contamination surface acts as a capacitor, as shown in Fig. 1, in which an equivalent circuit is drawn with a capacitor of ∼μF and resistors of several hundred kΩ connected in parallel. Hence, a phase difference arises between the current and the voltage, causing a hysteresis effect on the voltage–current curves [15]. As the sweep voltage frequency and electron density of plasma influence the hysteresis effect, the most convenient method is probably the use of a high frequency sweep voltage since the impedance of the equivalent capacitor decreases at high frequencies. An analysis shows that a 10 Hz sweep voltage frequency is regarded to be sufficient to minimize the contamination effect for studies of low density ionosphere [16]. However, such a fast voltage sweep produces a large amount of data which may not be downloaded to the ground with a limited downlink rate, and in fact the method has never been used in space previously.

The present paper describes the mechanical and electrical designs that have been used for the past several Korean satellites, including the KITSAT-3, KOMPSAT-1, STSAT-1, STSAT-2, as well as the Naro satellite. The electrical design includes adoption of a fast voltage sweep as these satellites, equipped with X-band antennas which can transmit scientific data to the ground with a rate as high as 10 Mbps, allow high frequency measurements. The result of the performance tests carried out on KOMPSAT-1 against simultaneous and independent measurements using an electron temperature probe on the same spacecraft is also discussed. Instrument designs and test results are described in Sections 2 and 3, respectively, and the summary is given in Section 4. We note here that, while the observations made by the LPs on the above-mentioned Korean satellites have been discussed in numerous papers, the description of the instruments themselves has never been reported previously.

2. Instrument design

Fig. 2 shows a general mechanical structure of an LP. The probe consists of a high purity tungsten rod, a guard ring made of stainless steel that reduces the edge effect as the same probe voltage is

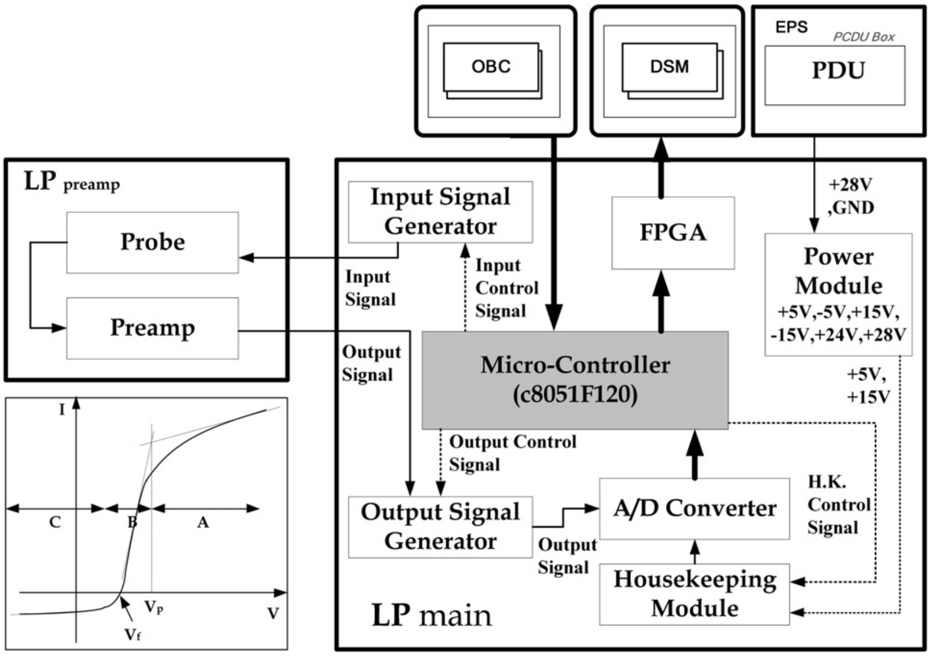

Fig. 3. System block diagram of the LP adopted for the Naro satellite.