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A ROCKET-BORNE LANGMUIR PROBE RESPONSE TO CONTINUOUS AND PULSED SWEEP MODES

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ABSTRACT

Nightime ionospheric electron density and temperature are measured using a rocket-borne Langmuir probe (LP) launched on board a SONDA III rocket from the Brazilian equatorial rocket launching station in Alcântara-MA, at 23:51 hrs (LT) on May 31, 1992. A sweep voltage varying between -1V and +2.5V is applied to the spherical LP sensor alternately in continuous and pulsed modes. In the continuous mode the effect of contamination of the sensor surface on the current collected by the sensor is clearly seen in the current-voltage characteristics and thereby on the electron temperature estimated, while this effect is practically absent in the pulsed mode operation. An electron temperature profile estimated from the LP data is compared with the IRI90 model profile.

1. INTRODUCTION

In-situ measurement of plasma density and temperature by Langmuir probes (LP) is known to be hampered by problems that originate from sensor geometry, sensor surface contamination, secondary electron emission from the probe surface, formation of plasma sheath surrounding the sensor surface, absence of proper return path for the current collected by the sensor etc (For details see Holmes and Szuszczewicz, 1975; Oyama, 1976 and references therein). Experiments have clearly shown that contaminated LPs consistently show hotter electron distributions than actually present in the medium. In conventional continuous sweep mode operation the LP measurements are affected by temporal variations in the probe's effective work function (Wehner and Medicus, 1952; Hirao and Oyama, 1972; Holmes and Szuszczewicz, 1975). Variation in the surface condition of the probe - the probe surface contamination effect - results in hysteresis in the current-voltage characteristics. Holmes and Szuszczewicz (1975) developed a new technique known as the Pulsed Plasma Probe technique to eliminate these problems and to improve the reliability of LP measurements. Szuszczewicz and Holmes (1975) conducted laboratory experiments using a LP operated alternately in continuous and pulsed sweep modes to determine the effectiveness of this new technique in eliminating the surface contamination effects and the associated hysteresis in LP current-voltage(I-V) characteristics. They reported that the pulse technique is, in fact, superior to the conventional continuous sweep approach.

A LP along with several optical diagnostic experiments was launched on board a Brazilian SONDA III rocket on May 31, 1992 at 2351hrs (LT) from the equatorial rocket launching station located in Alcantara (2.31°S, 44.4°W). The main scientific objective of the experiment was to study the nighttime equatorial ionosphere under quiet time conditions. The launch criterion was dictated by ground based airglow photometers and a Laser Radar operated at the launch site. At the time of launch an ionosonde at a nearby station, Fortaleza (3.9°S, 38°W), about 650km away from Alcantara, indicated rather quiet ionospheric conditions without the presence of Spread-F irregularities. The flight details are summarized below.

Launch site : Alcantara
Launch day/time : May 31, 1992; 2351hrs(LT)
Launch azimuth(mean) : 37.9 degrees
Launch elevation : 63.77 degrees
Apogee altitude : 282km
Flight duration : 510 seconds
Horizontal range : 410km

With the technical objective of comparing the performance characteristics, the LP experiment was operated alternately in continuous and pulsed sweep modes. The experiment functioned satisfactorily during both the ascent and descent of the rocket and measured height profiles of electron density and electron temperature. A brief description of the LP experiment and the results of a comparative study of the LP performance in the continuous and pulsed mode operations are presented here.

2. EXPERIMENT DETAILS

A gold plated metallic sphere of diameter 35mm mounted at the extremity of a short deployable boom made of fiberglass material was used as the LP sensor. The boom was mounted close to the outer edge of the mount plate inside the rocket nose cone and kept folded in vertical position before the launch. It was deployed to horizontal position soon after the ejection of the nose cone. The payload segment of the SONDA III rocket is shown schematically in Figure 1.

A sweep voltage varying between -1.0V and +2.5V in the continuous mode and between -0.5V and +1.25V in the pulsed mode in a period of about 2.6s is applied to the LP sensor to obtain both the electron density and the electron temperature. The continuous and pulsed sweeps are applied alternately in order to study the performance characteristics of the LP sensor in the two modes. In the continuous sweep mode the sensor potential remains at -1.0V for 41ms, increases linearly with time to 2.5V in about 1.5s and then remains at 2.5V for another 1.1s. In the pulsed sweep mode a train of short period pulses with peak amplitudes varying the same way as in the continuous sweep is applied to the sensor. The sensor potential in the pulsed mode has an amplitude almost half the corresponding amplitude in the continuous mode. That is to say, in the pulsed sweep mode the sensor remains at -0.5V for 41ms, increases linearly with time to about 1.25V in 1.5s and then remains at 1.25V for 1.1s.

The narrow pulses applied in the pulsed sweep mode have pulse widths of 160 μs and a repetition period of 640 μs. During the inter pulse period of 480 μs the LP sensor is maintained at zero potential with respect to the rocket body that is considered ground for all the potential measurements. During the period of 160 μs when the pulsed potential is applied to the sensor, the current collected by it is measured through a gate of width 40 μs using a very high input impedance current to voltage converter amplifier and a sample and hold circuit. The same system is used to measure the current collected by the sensor during the continuous sweep mode also. The block diagram of the electronic system is shown in Figure 2. For covering the large dynamic range of the sensor current varying in the range of a few nano amperes to several tens of microamperes, the current to voltage converter amplifier operates in two ranges, one with a gain of unity and the other with a gain of around 40. The output of the current to voltage amplifier is processed through three different channels to study the slowly varying as well as fast varying components in the sensor current.

3. RESULTS AND DISCUSSION

The I-V characteristic curves of the LP sensor observed at approximately 70, 100 and 200 seconds after launch corresponding to mean altitudes of around 100km, 150km and 260km are shown in Figures 3, 4 and 5 respectivley for both continuous and pulsed sweep modes of operation of the LP. The variation in the relative strength of the current collected by the sensor as a function of the potential applied to it for the potential range of 0V to +1.5V (1.25V in the pulsed mode) is shown in these figures. It should be noted here that in the

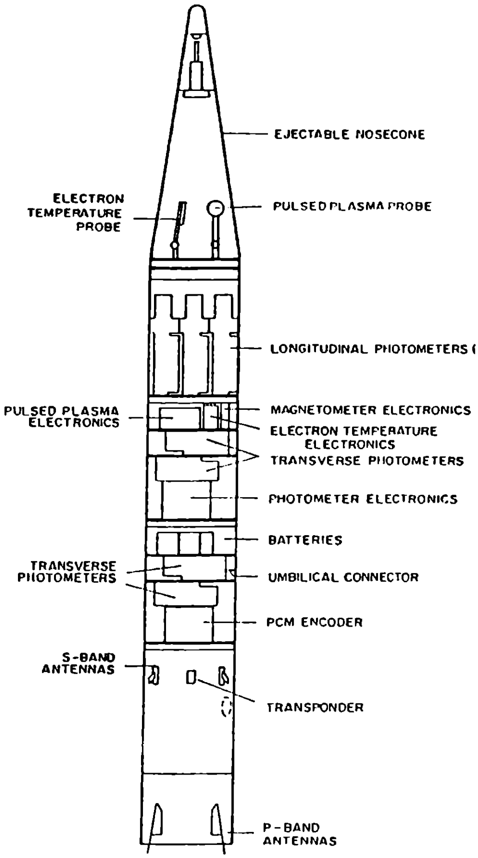

Figure 1. *Payload segment of the SONDA III rocket showing the location and mounting of the Langmuir Probe and other optical diagnostic experiments with their associated electronics systems.*

electronic system used for the signal processing, positive as well as negative current collected by the sensor is converted into a varying negative potential at the output of the current to voltage converter. In other words positive current collected by the sensor is folded on to the same side that represents the negative current collected by it. Thus the current minimum observed in all the curves, in fact corresponds to more or less zero current and therefore to the floating potential of the sensor.

The current collected by a spherical sensor immersed in a plasma is given by the approximate relation (see Spencer et al 1962),

$$I = \frac{Ane}{4}\left[\left(\frac{a}{r}\right)^2 v_s - \bar{v}_e exp\left(\frac{eV}{kT_e}\right)\right] \tag{1}$$

where A is the surface area of the sensor, n is the ambient plasma number density, e is the magnitude of the electronic charge, a is the radius of the plasma sheath shell surrounding the spherical sensor, r is the radius of the sensor, v_s is the sensor speed with respect to the ambient medium, v_e is the mean thermal velocity of electrons, V is the sensor potential with respect to the ambient plasma, k is the Boltzmann constant and T_e is the electron temperature. The first term within the brackets in equation (1) represents the positive ion current and the second term the electron current collected by the LP sensor. For positive sensor potentials if one assumes that the positive ion current is negligible compared with the electron current (the consequences of this approximation will be discussed later) and thereby neglects the positive ion term in equation (1), one can get the simple relation,

$$ln|I| = ln(Ane\bar{v}_e / 4) + \frac{eV}{kT_e} \tag{2}$$

Using equation (2) one can estimate the electron temperature from the slope of the linear portion of the ln(I) vs V characteristic curve. If I_1 and I_2 are the electron currents collected at sensor potentials V_1 and V_2 one can get from equation (2),

$$T_e = \frac{e}{k} \cdot \frac{V_2 \quad V_1}{ln|I_2| - ln|I_1|} \tag{3}$$

The electron temperature values thus estimated for continuous as well as pulsed mode operations of the LP are shown in Figures 6 and 7 for the upleg and downleg of the rocket trajectory respectively. Also given in Figures 6 and 7 is the IRI90 model estimate of the electron temperature. The following important observations can be made from these figures.

1. Electron temperature estimates made from the pulsed mode operation of the LP differ considerably from those made from the continuous mode operation.

2.IRI90 model temperature profile matches reasonably well the pulsed mode T_e profile, though at altitudes below about 150km the two profiles deviate considerably one from another.

To understand clearly these observations one has to look back into the limitations of the conventional LP technique. LPs operated with slow varying sweep are known to be affected by temporal variations in the effective work function of the probe resulting mainly from the probe surface contamination (for details see Holmes and Szuszcewicz, 1975 and references therein). Oyama (1976) presented a theoretical formulation of the problem using an equivalent circuit for the contamination of the probe surface, and tried to verify these theoretical results from laboratory experiments. He finds that the probe surface contamination results in considerable overestimation of T_e when the probe is operated at a sweep rate less than a few Hz and that this effect reduces considerably when the probe potential is swept at a higher rate, typically above 10Hz. The effect of surface contamination on a slow varying probe potential is to introduce a potential drop across the contamination layer and thereby to reduce the effective potential seen by the ambient plasma . T_e value estimated from the example given in figure 5 of Oyama (1976) using the equation 3 is at least an order of magnitude higher than the T_e value of 600^{o}K estimated by him using a clean probe and the value of 610^{o}K estimated using an unclean probe operated at a fast sweep rate (see figure 6 of Oyama, 1976). Szuszcewicz and Holmes (1975) report that their laboratory studies with conventional LPs give T_e estimates at times a factor of 2 higher than the estimates made using their pulsed technique. Thus one can easily find an explanation for the observation (1) above. Since the present sensor potential sweep rate is about 0.4Hz, much lower than the 10Hz limit observed by Oyama (1976), almost a factor of 2 difference between the T_e estimates made from the pulsed and continuous modes of operation of the LP can be attributed to the effect of probe surface contamination.

The fact that the electron temperature values estimated from the pulsed sweep mode operation of the LP are much closer to the IRI90 model estimates (observation 2 above) confirms the experimental results of Szuszczewicz and Holmes (1975) with a laboratory plasma that the pulse technique is superior to the conventional continuous sweep method. However the large deviation of the IRI90 temperature profile from the pulsed mode LP profile needs to be explained. Oyama and Hirao (1976) report a similar enhancement in the E-region T_e profile over the model neutral temperature profile and attribute this to the existence in this region, of two groups of electrons with different temperatures (see also Oyama and Hirao, 1985). Oyama et al (1983) also report that their T_e profile estimated from their electron temperature probe deviates considerably from the model neutral temperature in the lower E-region (100-120km) and attribute this to the additional heating of electrons caused by the currents that flow in this height region (see also Schlegel et al, 1983). But they find it difficult to explain why these deviations are larger at midlatitudes than in the equatorial region where the intense electrojet current flows. They also suggest that the high energy electrons identified probably with field aligned currents that flow into the winter hemisphere along the geomagnetic field lines and spread at the heights of around 150km, are also partly responsible for the enhancement in T_e observed in the E-region altitudes. Abe et al (1993) estimate model T_e profiles for the auroral region taking into account the joule heating due to perpendicular electric fields and solar EUV radiations. They find that the joule heating and solar EUV radiations can cause an enhancement in T_e at lower altitudes including the E-region. There is no reason why this effect should not be observed at equatorial latitudes where perpendicular electric fields are known to exist. Therefore, there are sufficient reasons to believe that the deviation in the pulsed mode T_e profile from the model profile at altitudes below 150km is genuine and is probably due to the IRI90 model being unrealistic in this region.

It should also be noted here that equation (2) relating the electron temperature to the potential applied to the LP sensor and the current collected is only an approximate one and is based on several not-so-realistic assumptions. Muralikrishna et al (1994) studied the consequences of assuming that the positive ion current is negligible and report that this can result in overestimating, leaving unaltered or even underestimating the actual electron temperature. But this is a second order effect and the deviation caused by this in the T_e profile, when compared with that caused by the probe surface contamination, seems to be negligible. From these considerations it seems to be quite logical to conclude that the pulsed mode operation of an LP gives realistic estimates of the electron temperature as indicated by its closeness to the IRI90 model profile especially at altitudes above 150km. Also, the deviation of the model profile from the pulsed mode LP profile below 150km seems to be due to inadequacies in the IRI90 model resulting from several factors like scarcity of experiment data, non inclusion of the joule heating effect in the model and inadequate knowledge of the dynamical processes operating in this region.

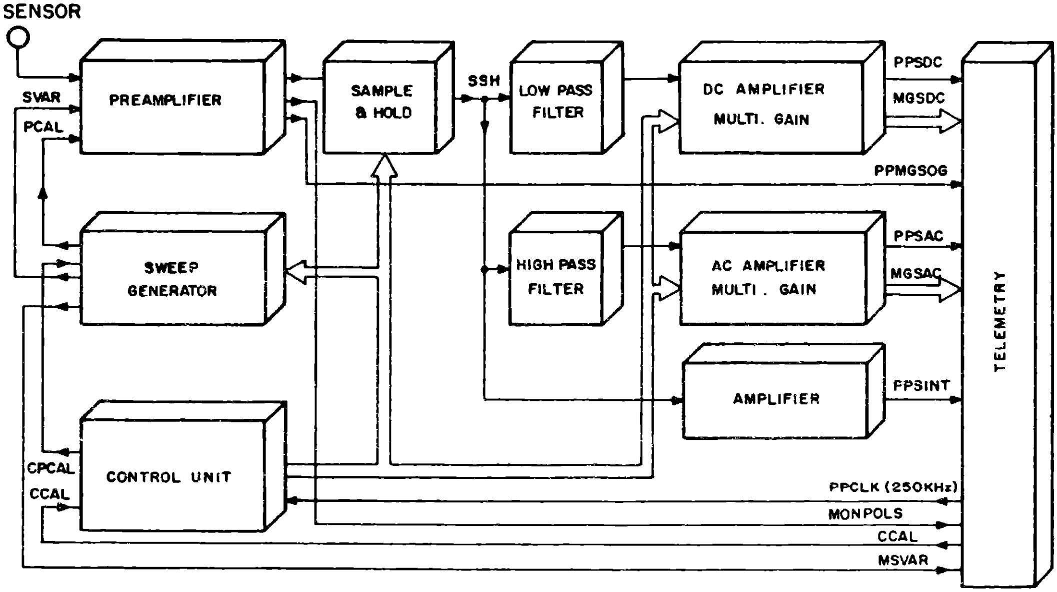

Figure 2. *Block diagram of the Langmuir Probe electronics system.*

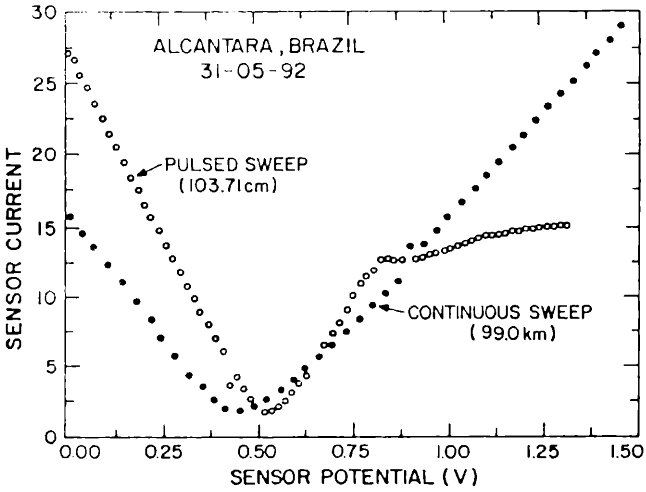

Figure 3. *Observed current-voltage characteristic curves for continuous and pulsed sweep mode operations of the Langmuir Probe corresponding to the height region of around 100km.*

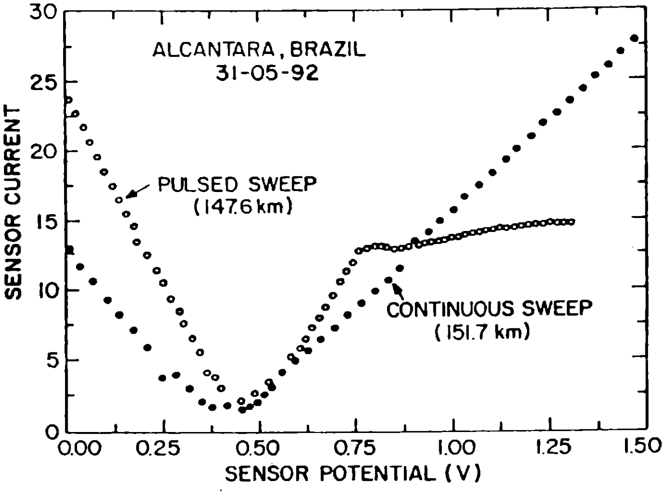

Figure 4. *Observed current-voltage characteristic curves for continuous and pulsed sweep mode operations of the Langmuir Probe corresponding to the height region of around 150km.*

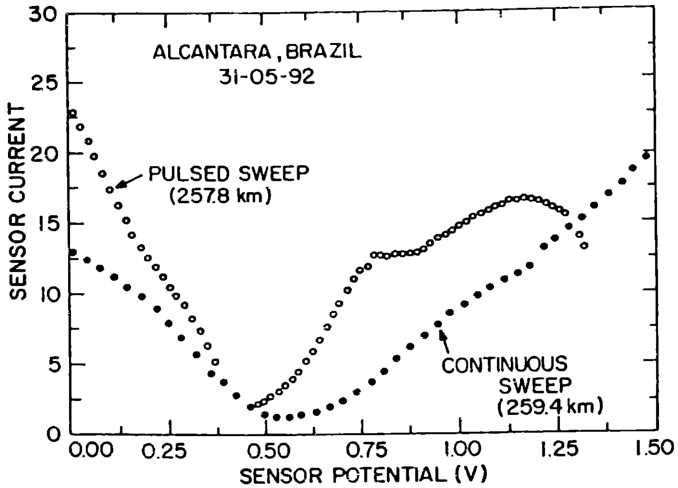

Figure 5. *Observed current-voltage characteristic curves for continuous and pulsed sweep mode operations of the Langmuir Probe corresponding to the height region of around 260km.*

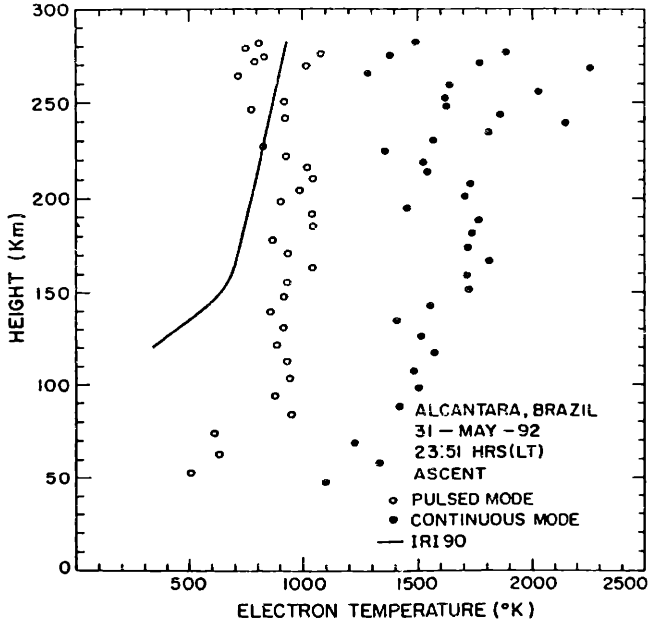

Figure 6. *Height profile of the estimated electron temperature for continuous and pulsed sweep mode operations of the LP compared with the IRI90 model profile for the upleg of the rocket trajectory.*

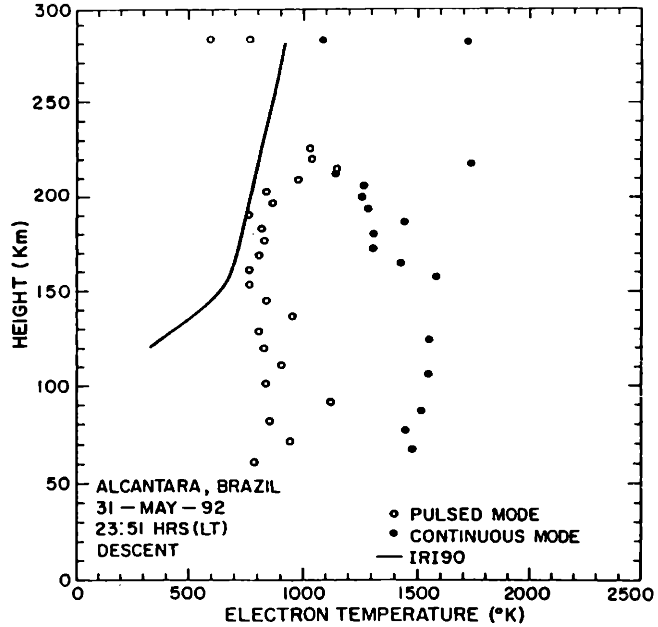

Figure 7. *Height profile of the estimated electron temperature for continuous and pulsed sweep mode operations of the LP compared with the IRI90 model profile for the downleg of the rocket trajectory.*

4. CONCLUSIONS

From this comparative study of the Langmuir Probe performance in continuous and pulsed sweep modes of operation one can see that there is a marked difference in the current-voltage characteristic of a Langmuir probe operated in pulsed mode when compared with that operated in continuous mode. In conformity with the laboratory observations of Szuszczewiz and Holmes (1975) the effect of surface contamination on the LP current-voltage characteristic seems to be practically absent in the pulsed mode operation of the LP. The IRI model electron temperature profile for the equatorial region seems to be unrealistic, especially for altitudes below 150km, giving electron temperatures lower than those estimated from the LP measurements.

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