Exposed High-Voltage Source Effect on the Potential of an Ionospheric Satellite

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A pulsed, high-voltage source, which is able to draw a current from the surrounding plasma, is seen to induce large changes in the potential of an ionospheric satellite (the Iowa Plasma Diagnostics Package flown on Space Shuttle flight STS-51F). This, in turn, may affect the operation of other instruments that use the chassis of the satellite as a ground for electrical circuits. The magnitude of the change in satellite potential is dependent upon both the orientation of the high-voltage source, relative to the plasma flow, and the characteristics of the high-voltage source. When the satellite is grounded to the Shuttle Orbiter, this effect is sufficient to change the potential of the Orbiter by a small, but noticeable, amount.

Nomenclature

A_e = surface area of the PDP that will collect electrons
A_i = surface area of the PDP that will collect ions
e = charge of the electron
h = height of the main body of the PDP
h' = height of the "top cap" of the PDP
$I_{e,\,ins}$ = electron current collected by all of the PDP's instruments
$I_{e,\,pr}$ = electron current collected by the Langmuir probe
$I_{e,\,LEP}$ = electron current collected by the LEPEDEA
$I_{e,\,sc}$ = electron current collected by the PDP chassis
$I_{i,\,ins}$ = ion current collected by all of the PDP's instruments
$I_{i,\,sc}$ = ion current collected by the PDP chasis
k = Boltzmann's constant
m_e = mass of the electron
n_e = electron density
n_i = ion density
r = radius of the main body of the PDP
r' = radius of the "top cap" of the PDP
T_e = electron temperature
v_o = orbital velocity of the PDP

Introduction

A SPACECRAFT traveling in the Earth's ionosphere has no external electrical ground available for it to use as a reference for potential measurements. As a consequence, such spacecraft are susceptible to different types of charging phenomena that may alter the potential of the spacecraft chassis.[1,2] From July 29 to August 6, 1985, a satellite designed and built by the University of Iowa's Department of Physics and Astronomy, the Plasma Diagnostics Package (PDP), was flown as part of the Spacelab 2 payload on Space Shuttle flight STS-51F at an altitude of 325 km. The PDP is a cylindrical spacecraft 106.68 cm (42 in.) in diameter and 66.04 cm (26 in.) in height composed of 14 different instruments designed to study the plasma and electromagnetic environment near the Shuttle Orbiter. A diagram is shown in Fig. 1.

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The PDP skins are constructed of aluminum and are covered by multilayered insulation (MLI) blankets followed by an outer dielectric layer of beta cloth (teflon-coated fiberglass) overlaid with a conducting aluminum wire mesh electrically grounded to the chassis of the PDP via bolts and staples through the MLI. The MLI consists of a singly aluminized kapton layer on the outside (aluminum sides facing inward) and 10 layers of doubly aluminized mylar separated by dacron net on the inside with grounding straps used to electrically bond the MLI to the structure.

During the Spacelab 2 mission, the PDP made measurements from the payload bay, from the Remote Manipulator

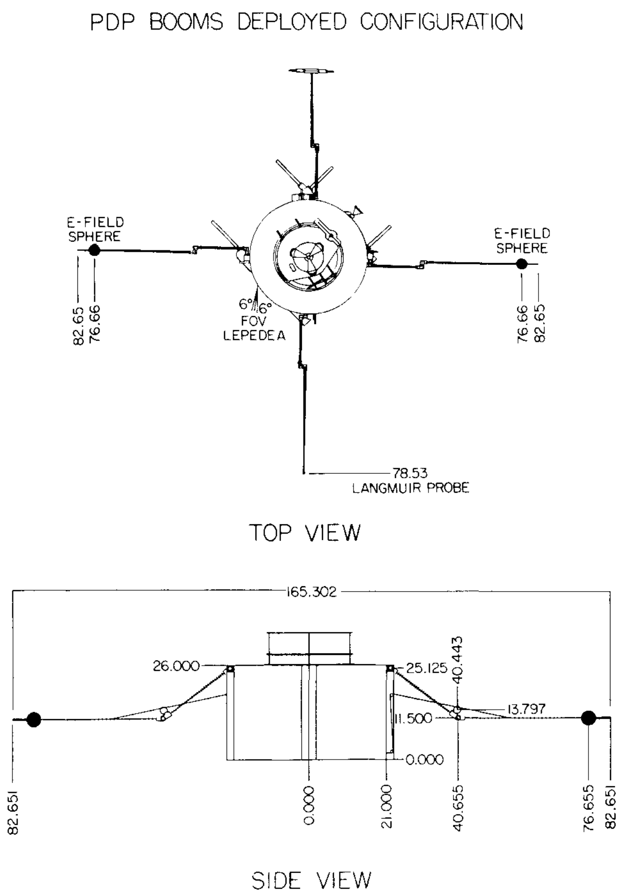

Fig. 1 Diagram of the PDP with booms deployed. Relevant distances are indicated in inches.

System (RMS), and for a period of 6 h as a free-flying subsatellite. This paper will show how some of the measurements made with a Langmuir probe and a dc Electric Fields instrument (utilizing the E-field spheres) on the PDP were affected by a pulsed, high-voltage source (LEPEDEA).

Instrumentation

A Langmuir probe on the PDP was used to make measurements of electron temperature, electron density, fluctuations in the electron density, and plasma potential. The Langmuir probe consisted of a 3-cm-diam spherical, gold-plated sensor and supporting circuitry. This circuitry was designed to alternate between two modes, which we refer to as the sweep mode and the lock mode.

During the sweep mode the bias voltage of the Langmuir probe was swept from 10 to -5 V, relative to the chassis of the PDP, in discrete steps of 0.125 V at a rate of 120 steps/s. A graph of the log of the current collected by the Langmuir probe during this time as a function of the bias voltage is typically referred to as a Langmuir curve. As shown, for example, by Huddlestone and Leonard,[3] a Langmuir curve allows us to calculate the electron density, electron temperature, and plasma potential. An example of a typical Langmuir curve is shown in Fig. 2a. In Fig. 2a and in all subsequent figures, the times given are in Universal Time (UT).

Following the sweep mode, the bias voltage on the Langmuir probe returned to 10 V where it remained for 11.8 s. During this time, the data collected by the probe, which were again sampled at a rate of 120 steps/s, allow us to measure electron density fluctuations. An example of the lock mode data, sampled through a 6–40-Hz filter, is shown in Fig. 2b. A Langmuir probe similar to the one used on the Spacelab 2 mission is discussed in more detail by Murphy et al.[4]

The dc Electric Fields instrument on the PDP consisted of two spherical unbiased high-impedance probes and associated electronics. The two sensors are visible in Fig. 1 and are labeled E-field spheres. In this paper, we are concerned with only one type of dc measurement that was made. The average of the dc potentials of the two spheres, V_a and V_b relative to the chassis of the PDP, $(V_a + V_b)/2$, was measured once every 1.6 s. It is important to note that the measurements made by the Langmuir probe and the dc Electric Fields instrument complement each other in that the Langmuir probe was a low-impedance sensor that measured current at a controlled bias level and the dc Electric Fields instrument utilized high-impedance floating probes that measured the potential at near-zero current.

The last instrument that will be discussed in this paper is the Low Energy Proton Electron Differential Energy Analyzer (LEPEDEA). As can be seen in Fig. 1, the LEPEDEA was mounted on the circumference of the PDP. It has two particle collectors open to the ionosphere, one designed to detect electrons and the other, ions. The two openings are separated by a curved plate to which a pulsed high-voltage is applied. The combined cross-sectional area of the openings to the electron and ion detectors is 6.69 cm^2 (1.04 $in.^2$). The high-voltage plate is 5.26 cm (2.07 in.) wide and extends into the LEPEDEA for a distance of 9.83 cm (3.87 in.). At time $t = 0$, the bias voltage on the LEPEDEA plate switched from 0 to 2.2 kV, relative to the chassis of the PDP, where it remained for 0.2 s. During the following 1.4 s, the bias voltage then decayed exponentially with a $1/e$ time of 0.16 s, the entire cycle requiring 1.6 s. The operation of the LEPEDEA is discussed in more detail by Frank et al.[5]

Anomalous Results

During the 6 h of free flight, an anomaly was detected in both the sweep and lock mode data collected by the Langmuir probe. An example is shown in Fig. 3. Figure 3a indicates that the normal Langmuir curve is interrupted by a "bite out" in the current collection. This bite out always maximizes approximately 0.2 s after the start of the voltage sweep.

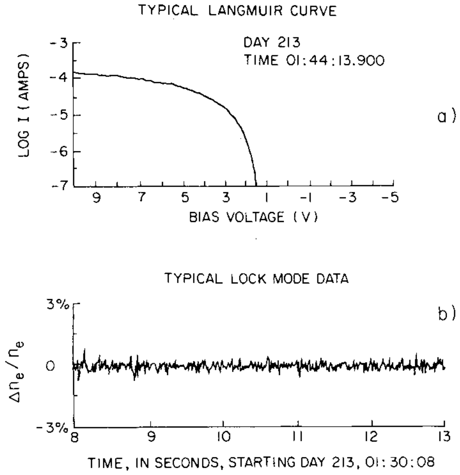

Fig. 2 Examples of: a) a typical Langmuir curve and; b) typical lock mode data.

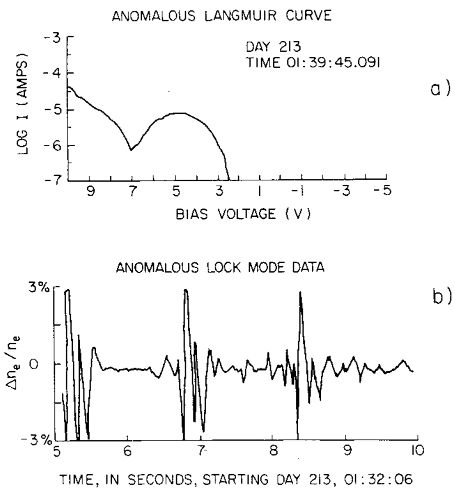

Fig. 3 Examples of: a) an anomalous Langmuir curve and; b) anomalous lock mode data.

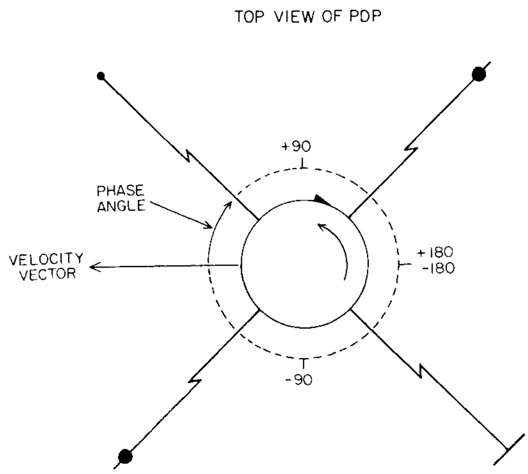

Fig. 4 Definition of the Langmuir probe phase angle. The PDP is rotating counterclockwise in the plane of the paper.

Further examination of a series of Langmuir curves indicates that the magnitude of the anomaly is dependent upon the orientation of the PDP, which was spinning about its cylindrical axis with an inertial period of 13.06 s. This orientation is defined by a phase angle, which is the angle between the velocity vector of the PDP and the vector that points from the center of the PDP to the Langmuir probe,

Fig. 4. In this figure, the PDP is rotating counterclockwise in the plane of the paper. The Langmuir probe entered the sweep mode every 12.8 s. Consequently, if the PDP started a voltage sweep when the phase angle was −180 deg, the next sweep would have begun when the phase angle was −172.9 deg. The difference in phase angles occurs because the PDP rotates through 352.9 deg in 12.80 s. Therefore, even though the PDP is rotating in a counterclockwise direction, a graph of phase angle at the start of a sweep mode vs time would show the Langmuir probe apparently precessing in a clockwise direction. A series of Langmuir curves that shows the dependence of the anomaly on the phase angle is shown in Fig. 5. These data indicate that the anomaly maximized at a phase angle of about −55 deg.

As seen in Fig. 3b, the lock mode data indicate that some type of interference, which we hereafter refer to as noise, was affecting the Langmuir probe once every 1.6 s. The anomaly in the lock mode data was present even during times when the PDP was grounded to the RMS of the Shuttle Orbiter. However, the magnitude of the resulting anomaly was reduced in comparison to that seen during free flight.

Like the Langmuir probe measurements, the dc potential measurements taken during free flight also had an unexpected character. As is shown in Fig. 6, the average potential of the spheres relative to the PDP varied with the spin phase of the spacecraft. In Fig. 6, the potential between the spheres and the PDP varies by about 2.1 V over the spin cycle. At other times during free flight, this variation in potential was as much as 3.0 V, depending on the local plasma conditions. The variation in potential always reached its maximum positive value when the phase angle of the Langmuir probe was about −55 deg.

Source of the Interference

Several reasons led us to believe that the noise detected by the Langmuir probe during PDP free flight was not due to an instrument malfunction. First, at all other times throughout the mission, the probe appeared to function as expected, and no anomaly was detected until data reduction had begun. Second, noise seen by the dc Electric Fields Instrument was coincident in time with the noise seen by the Langmuir probe. Also significant was the fact that the Langmuir probe noise recurred with a period of 1.6 s. This is important in that several instruments on the PDP were designed so that one complete "cycle" would require 1.6 s. As was mentioned previously, the LEPEDEA is just such an instrument. The temporal relation between the bias voltage on the LEPEDEA and the bias voltage on the Langmuir probe is illustrated in Fig. 7. The "ringing" detected in the lock mode data occurred at precisely the times that the bias voltage on the LEPEDEA switched from 0 to 2.2 kV. This, and the fact that, throughout the mission, whenever the LEPEDEA was turned off, the anomalies seen by the Langmuir probe and the dc Electric Fields Instrument disappeared, led us to believe that, in some way, the LEPEDEA was responsible for the anomalous data.

This suspicion was strengthened by the fact that the phase-angle dependence, Fig. 5, shows strong indications of being a dependence upon the orientation of the LEPEDEA. In Fig. 5, we see that the Langmuir curves, which have an anomalous character, occur between a phase angle of about −110 and 30 deg. This corresponds to time when the LEPEDEA phase angle was between −53 and 87 deg. Sweeps taken when the Langmuir probe phase angle was −55 deg corresponded to times when the LEPEDEA was approximately in ram. Thus, the anomalies were largest when the LEPEDEA was in the ram of the plasma flow and smallest when it was in wake. The reason for this dependence will be discussed in the next section.

Discussion

When working with laboratory plasmas, it is possible to use an externally grounded electrode, whose potential will not change, as a reference point for potential measurements. However, no such electrical ground is available when dealing with a spacecraft in the ionosphere. In such a situation, we must treat the system of the spacecraft and the instruments

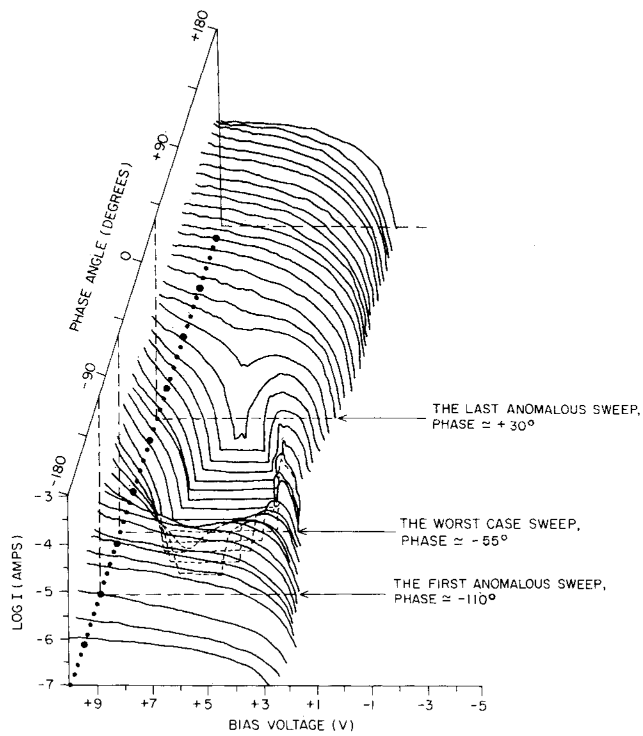

Fig. 5 Series of Langmuir curves taken at various phase angles. Time increases with increasing phase angle.

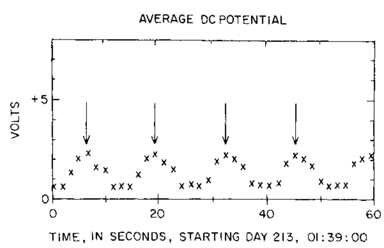

Fig. 6 Average dc potential of the PDP as measured by the dc Electric Fields instrument. The arrows indicate the times when the LEPEDEA is approximately in ram.

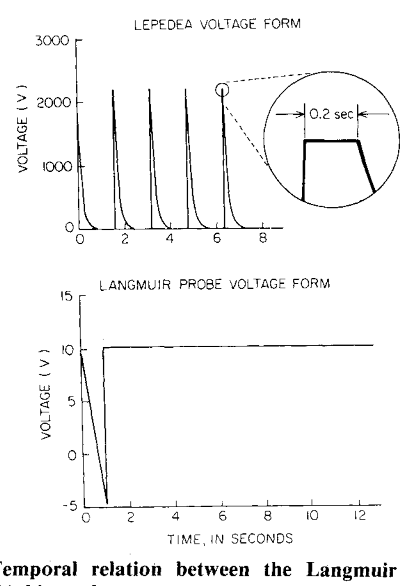

Fig. 7 Temporal relation between the Langmuir probe and the LEPEDEA bias voltages.

mounted on it as a "double probe," following the method originally proposed by Johnson and Malter.[6] When two probes are biased with respect to one another but insulated from ground, the entire system will "float." An important consequence of this is that the total current collected by the system must be zero. That is, any electron current collected by the system must be balanced by an equal ion current. In our case, the condition that the system be floating is

$$I_{i,\ sc} + I_{i,\ ins} - I_{e,\ sc} - I_{e,\ ins} = 0 \tag{1}$$

where $I_{i,\ sc}$, $I_{e,\ sc}$, $I_{i,\ ins}$, and $I_{e,\ ins}$ are defined as the ion and electron currents to the PDP spacecraft structure and the instruments, respectively. We are able to obtain expressions for $I_{i,\ sc}$ and $I_{e,\ sc}$ in the following manner.

After release from the Shuttle, the PDP had an orbital velocity of about 7.7 km/s. Analysis of the uncontaminated Langmuir probe data indicated that the electrons had a typical temperature of about 2500 K and a typical density of $1\text{-}5 \times 10^5$ cm^{-3}, in general agreement with previous measurements. If we assume that the ions and electrons are in thermal equilibrium, we find that the thermal velocity of an electron was about 180 km/s and the thermal velocity of atomic oxygen, the predominant ion in the F2 region, about 1.1 km/s. Since the orbital velocity of the PDP was approximately a factor of 7 greater than the thermal velocity of the ions, most of the ions would have impacted the PDP on the side facing the ram of the plasma flow, the ion current thus consisting of the ions swept out by the front surface of the PDP. The equation describing ion current collection by the spacecraft is

$$I_{i,\ sc} = A_i e n_i v_o \tag{2}$$

where A_i is the front surface area of the PDP, e the charge of the ion, n_i the ambient ion density (we assume $n_i \simeq n_e$), and v_o the orbital velocity of the PDP. Since the ion current consists of those ions that are rammed out by the motion of the PDP, we will approximate A_i by $(2rh + 2r'h')$, where r, h are the radius and height of the main body of the PDP, and r', h' are the radius and height of the "top cap," Fig. 1.

The thermal velocity of the electrons is greater than the orbital velocity of the PDP by almost a factor of 25. Consequently, all surfaces of the PDP will collect electron current, not just the ram side. We assume that the electrons had a Maxwellian distribution given by

$$f_e(v) = n_e \left[\frac{m_e}{2\pi k T_e}\right]^{3/2} \exp\left[\frac{-m_e v^2}{2kT_e}\right] \tag{3}$$

The electron current to the PDP at a potential V less than the plasma potential V_p, and measured relative to V_p, consists of those electrons with energies greater than $|eV|$ that strike the PDP, and is given by

$$I_{e,\ sc} = A_e e n_e \left[\frac{kT_e}{2\pi m_e}\right]^{1/2} \exp\left[\frac{eV}{kT_e}\right] \tag{4}$$

where A_e is the surface area of the PDP that will collect electrons, e the charge on the electron, n_e the electron density, k Boltzmann's constant, T_e the electron temperature, and m_e the electron mass. Since the electrons may strike all surfaces of the PDP, we approximate A_e by $(2\pi r^2 + 2\pi rh + 2\pi r'h')$.

We now need expressions for $I_{i,\ ins}$ and $I_{e,\ ins}$. The cross-sectional collecting areas of all of the instruments on the PDP are several orders of magnitude smaller than A_i; consequently, we should be justified in neglecting $I_{i,\ ins}$ altogether. The only instruments on the PDP expected to draw significant amounts of electron current from the plasma, due to their positive bias voltages, are the Langmuir probe and the LEPEDEA. We can rewrite Eq. (1) as

$$I_{i,\ sc} - I_{e,\ sc} - I_{e,\ pr} - I_{e,\ LEP} = 0 \tag{5}$$

where the subscripts pr and LEP refer to current collected by the Langmuir probe and LEPEDEA, respectively. We can solve the preceding equation to determine the potential of the chassis of the PDP. Since the LEPEDEA has a very small collecting area and its bias voltage is large only for about 0.3 s, during most of its 1.6-s operational cycle it should draw negligible current from the ionosphere. Therefore, we will first solve for the floating potential by setting $I_{e,\ LEP}$ to zero. Substituting Eqs. (2) and (4) into Eq. (5), with $I_{e,\ LEP}$ set to zero, we find that the "floating potential" of the PDP is given by

$$V = \frac{+kT_e}{e} \ell n \left[\frac{A_i e n_i v_o - I_{e,pr}}{A_e e n_e (kT_e/2\pi m_e)^{1/2}}\right] \tag{6}$$

Using the values for n_e, T_e, and the additional constants given in Table 1, we may determine the nominal floating potential of the PDP once we know $I_{e,pr}$. Analysis of Langmuir curves collected under the plasma conditions listed in Table 1 reveals that the corresponding value of $I_{e,pr}$ is approximately 14 μA, which would give a value of -0.90 V for the floating potential of the PDP. The resulting magnitudes of $I_{e,sc}$ and $I_{i,sc}$ would be about 93 and 107 μA, respectively. (Ignoring the presence of $I_{e,pr}$, i.e., setting $I_{e,pr}$ to zero, would have given a value for V_{fl} of -0.86 V. As we shall see momentarily, a change of 0.04 V is about 2 orders of magnitude smaller than the effect that is responsible for the appearance of the anomalous data. Consequently, we would be justified in ignoring $I_{e,pr}$ altogether.)

We turn next to the intervals when the LEPEDEA voltage was large and positive. As was mentioned previously, we believe that the cause of the anomalous data discussed in the preceding sections was somehow related to the operation of the LEPEDEA. The most likely explanation for the appearance of the anomalous Langmuir curves is that the bias voltage of the Langmuir probe, relative to the plasma, was changing unexpectedly during the course of a sweep. One other possible explanation, that the conditions in the plasma itself were changing, was not supported by data from other instruments on the PDP. An examination of all anomalous Langmuir curves showed that, by the time the Langmuir probe bias voltage had stepped to 4 V, the cause of the anomaly seemed to have subsided, as the remainder of the anomalous Langmuir curve appeared nominal. Under the assumption that whatever was responsible for the anomaly had completely subsided by the time the probe's bias voltage was 4 V and that the conditions in the plasma remained unchanged during the course of a sweep, we were able to analyze the anomalous sweeps as follows. The Langmuir curve shown in Fig. 8 was taken when the plasma conditions were similar to those given in Table 1. In this figure, when the bias voltage of the Langmuir probe was 9 V, the probe collected about 6 μA of current from the plasma. Under normal conditions we would not collect this current until the bias voltage of the probe was 7.3 V. Therefore, we conclude that, at the time the probe bias voltage was supposed to be 9 V, relative to the original floating potential of the PDP, it was actually 7.3 V. As is shown in Fig. 9, this procedure allowed us to determine the potential of the PDP, relative to the original floating

Table 1 Constants used in the calculation of the floating potential

Geometry of satellite:	
Electron collecting area A_e, m^2	4.395
Ion collecting area A_i, m^2	0.830
Height of main body h, cm (in.)	66.04 (26)
Height of "top cap" h', cm (in.)	21.97 (8.65)
Radius of main body r, cm (in.)	53.34 (21)
Radius of "top cap" r', cm (in.)	28.58 (11.25)
Orbital parameters:	
Electron density n_e, $\times 10^5$ cm^{-3}	1
Ion density n_i, $\times 10^5$ cm^{-3}	1
Electron temperature T_e, K	2500
Orbital velocity of PDP v_o, km/s	7.7

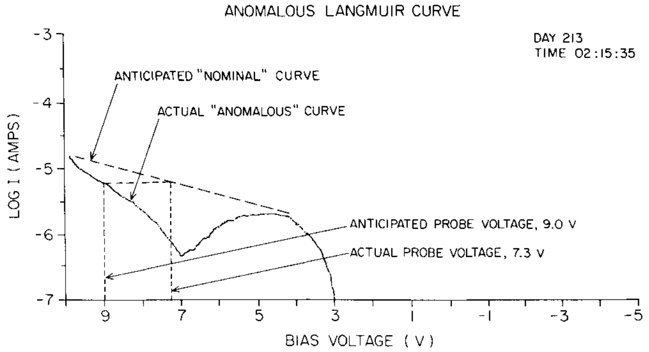

Fig. 8 Illustration of the method used to determine the actual Langmuir probe bias voltage, relative to the original floating potential of the spacecraft.

potential, as a function of time. (This cannot be done with the average dc potential measurements by the E-field spheres, since the dc potential is sampled only once every 1.6 s.) The potential of the PDP dropped for about 0.2 s after the beginning of a sweep and then spent the next 0.2 s recovering to its original value. The implications of this are as follows.

Recall that the current balance equation, Eq. (5), must be satisfied at all times. We have four currents contributing to current balance. $I_{i,sc}$ is a constant, independent of the floating potential of the PDP, $I_{e,sc}$ depends on the floating potential, which we can determine as in Fig. 9, and $I_{e,pr}$ was measured directly. This allows us to solve for our one remaining unknown, $I_{e,LEP}$. A graph of $I_{e,LEP}$ as a function of time, assuming the plasma conditions given in Table 1, is given in Fig. 10. Time $t = 0$ is the time when the bias voltage on the LEPEDEA switches from 0 to 2.2 kV. Due to the sampling rate of the Langmuir probe data, 120 Hz, we were unable to determine the form of $I_{e,LEP}$ between 0 and 0.050 s. Consequently, this portion of the graph has been left blank. Also, we were unable to obtain $I_{e,LEP}$ after about 0.4 s, since it was difficult to establish with any accuracy when the predominant source of electron current changed from $I_{e,LEP}$ to $I_{e,sc}$.

In spite of these difficulties, the significance of Fig. 10 is that it shows conclusively that the LEPEDEA must be drawing significant amounts of electron current from the ionosphere. At time $t = 0.2$ s, the LEPEDEA is drawing about 100 μA of electron current, compared with 107 μA for the magnitude of $I_{i,sc}$. Thus, the LEPEDEA current is large enough that the potential of the PDP must drop by several volts in order to maintain current balance. In the example presented here, $n_e \simeq 1 \times 10^5$ cm^{-3}, $T_e \simeq 2500$ K, the potential of the PDP dropped by about 4 V. However, in some cases, when the Langmuir probe phase angle was about -55 deg, the resulting Langmuir curves indicated an even larger drop in spacecraft potential, Fig. 5. Also, by comparing the magnitude of the noise seen in the lock mode data during these worst-case events with the noise seen when the plasma conditions were similar to those in Fig. 8, we believe that, in some cases, the potential of the PDP may have dropped by as much as 10 V.

The previous discussion indicates that it is current collection by the LEPEDEA that is responsible for the anomalous data reported by both the Langmuir probe and the dc Electric Fields instrument. We must now show that this can explain the actual appearance of the anomalous data and also the dependence of the anomaly on the phase angle. We begin with a discussion of the Langmuir probe sweep mode data. As was shown in Fig. 7, the bias voltage on the LEPEDEA switches from 0 to 2.2 kV at the same time that the Langmuir probe enters the sweep mode. However, as was shown in Fig. 9, the maximum change in spacecraft potential does not occur until 0.2 s after the start of the sweep. This 0.2-s delay occurs because at time $t = 0$ the bias voltage on the LEPEDEA switches from 0 to 2.2 kV and remains at this level for 0.2 s. The situation is similar to what happens when one charges/

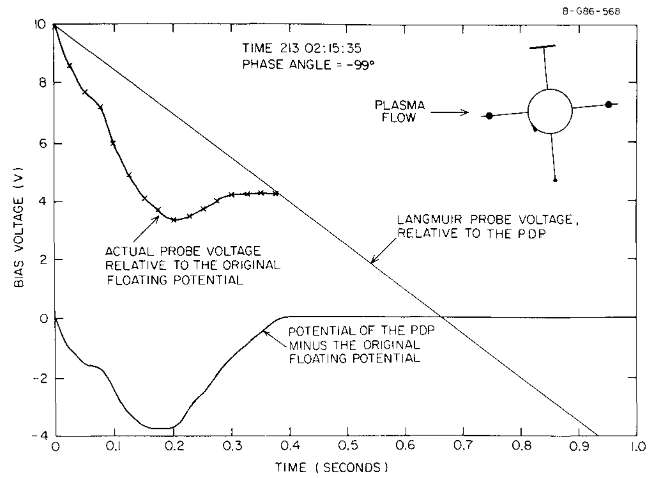

Fig. 9 Potential of the Langmuir probe and the PDP relative to the original floating potential.

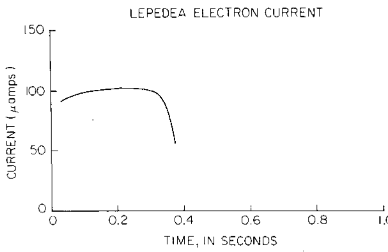

Fig. 10 Predicted value of the LEPEDEA electron current, $I_{e,LEP}$, vs time. Time $t = 0$ corresponds to the time when the LEPEDEA bias voltage switched from 0 to 2.2 kV.

discharges a capacitor. At $t = 0$, the LEPEDEA bias voltage is large and positive, thus the LEPEDEA can draw a large electron current from the ionosphere and the PDP begins to charge to a negative potential. At $t = 0.2$ s, the bias voltage on the LEPEDEA begins to decrease. Consequently, the electron current collected by the LEPEDEA also decreases and the PDP begins to "discharge" to its original potential.

As can be seen in Fig. 9, the PDP potential wave form appears "rounded off" at early times. We have examined the possiblility that this rounding could be related to a spacecraft-plasma circuit. Based on an electron density of 1×10^5 cm^{-3}, we calculate a plasma sheath resistance of about 10 kΩ, ignoring magnetic field effects. If the rounding off of the spacecraft potential waveform occurred because the current to the spacecraft could only vary with a time constant given by $\tau \approx L/R \approx 0.2$ s or $\tau \approx RC \approx 0.2$ s, for a simple circuit this would require values for the inductance L or the capacitance C, which are unrealistically large. Similarly, an examination of the Langmuir probe circuit gives no indication that any of its components could be responsible for producing the effect either. We have been informed that the LEPEDEA voltage form was nominal in the high-voltage range during the time of observation,[7] consequently, a satisfactory explanation of the PDP potential waveform is lacking.

The appearance of the lock mode (6–40 Hz) data is understood as follows. As was shown in Fig. 9, we were able to deduce the potential of the chassis of the PDP, as a function of time, after the voltage pulse to the LEPEDEA. Consequently, we also know that the actual bias voltage of the Langmuir probe would be, relative to the plasma, during the lock mode. This is shown in Fig. 11a, where time $t = 0$ again corresponds to the start of the voltage pulse on the LEPEDEA and the plasma conditions are those given in Table 1. Using a nominal Langmuir curve, Fig. 2a, we then determine the current collected by the Langmuir probe during the lock mode by reversing the process illustrated in Fig. 8. The current curve in the lock mode is shown in Fig. 11b for the initial 1.0 s of the 1.6-s cycle of the LEPEDEA voltage. By taking the fast

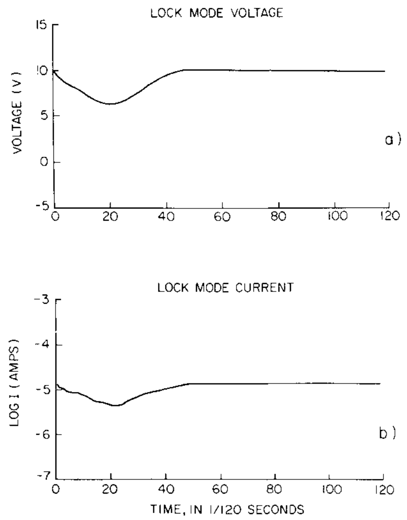

Fig. 11 Actual Langmuir probe bias voltage during the lock mode, relative to the original floating potential (a) and computation of the current collected by the Langmuir probe during lock mode (b). Time $t = 0$ corresponds to the time when the LEPEDEA bias voltage switched from 0 to 2.2 kV.

Fourier transform of these data, Fig. 11b, we then isolate the contribution of the 6–40-Hz components, see Fig. 12. In comparing Fig. 12 with Fig. 3b, we notice that the general oscillatory form seen in Fig. 12 is very similar to that seen in the actual data, although the finer details appear somewhat different. We should note that, in an attempt to recreate the ringing seen in Fig. 3b, we have ignored the presence of any rapid density fluctuations, and, thus, cannot expect our prediction, Fig. 12, to agree entirely with the actual data, Fig. 3b.

Next, we need to explain the dependence that the anomaly has on the orientation of the PDP. As was previously mentioned, the magnitude of the anomaly recorded by both the Langmuir probe and the dc Electric Fields instrument maximizes whenever the LEPEDEA is in ram. We would expect the LEPEDEA to draw less current when the local electron density, i.e., the electron density near its opening, is small, and more current when the local electron density is large. If we ignore $I_{e,\mathrm{pr}}$, we may rewrite Eq. (5) as

$$I_{e,\mathrm{LEP}} = e\, n_e^*(\theta)\, f(V)$$

$$= e n_e (A_i v_o - A_e [kT_e / 2\pi m_e]^{1/2} \exp[eV/kT_e]) \qquad (7)$$

where $n_e^*(\theta)$ is the local electron density "seen" by the LEPEDEA, θ the LEPEDEA phase angle, and $f(V)$ some function of its bias voltage. It is well established that the wake of an ionospheric satellite is a region of depleted electron densities. Therefore, when the LEPEDEA is facing the wake of the PDP, the local electron density, $n_e^*(\theta)$, will be significantly less than the local electron density seen in ram. Thus, the magnitude of $I_{e,\mathrm{LEP}}$ when the LEPEDEA is in the wake will be correspondingly reduced and current balance will be achieved with virtually no change in spacecraft potential. Consequently, no anomaly is detected when the LEPEDEA is in the wake.

Finally, the measurements of the average potential on the E-field spheres, relative to the chassis of the PDP, can also be easily understood. With the LEPEDEA voltage pulsed to 2.2 kV, the potential between the PDP (which becomes more negative) and the spheres (still close to the original floating potential) must increase. We note that this potential measurement was taken once every 1.6 s and always 0.166 s after the LEPEDEA voltage pulse. We can compare the potential change measured by the dc Electric Fields instrument with that determined from the Langmuir probe as in Fig. 9. In so doing, we find that the former is generally somewhat smaller than the latter, an effect due to low-pass filtering in the dc Electric Fields instrument. The Langmuir probe measurements and the dc potential measurements are, however, in general agreement.

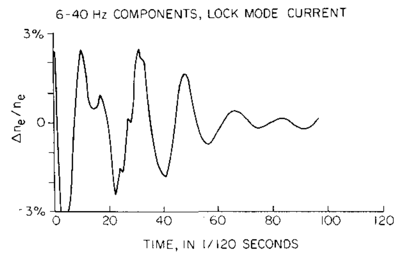

Fig. 12 Computed lock mode output from the 6–40-Hz channel. Time $t = 0$ corresponds to the time when the LEPEDEA bias voltage switched from 0 to 2.2 kV.

Conclusions

Our experience suggests that an exposed, positive high-voltage source on an ionospheric satellite can act as a source of electron current to the spacecraft chassis. This may, in turn, affect the operation of other instruments that use the chassis of the satellite as an electrical ground by altering the spacecraft potential. This change in spacecraft potential is dependent upon the orientation of the high-voltage source, relative to the plasma flow. It is believed that this problem can be minimized in the future by placing a grounded grid on the opening of the high-voltage source so as to limit the collection of thermal electrons.

The fact that the effect was also detectable in the lock mode data when the PDP was grounded to the Orbiter indicates that the pulse of electron current collected by the LEPEDEA was sufficient to change the potential of the Shuttle by a small, but noticeable, amount. Most of the body of the Shuttle is covered with an insulating material. The area of the Shuttle believed to be most responsible for current collection is the main engines. Because the surface area of the main engines is approximately one order of magnitude greater than that of the PDP, the current pulse to the LEPEDEA may have shifted the potential of the Orbiter by as much as −1 V when the main engines were in the Orbiter's wake. If the potential of the Orbiter had shifted by more than −1 V the appearance of the Langmuir probe sweep mode data would have been affected. Since this did not occur, −1 V is an upper bound on the change in potential of the Shuttle.

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