DESIGN AND TESTING OF THE FLOATING POTENTIAL PROBE FOR ISS

G. Barry Hillard, Dale C. Ferguson, and David B. Snyder
NASA Glenn Research Center
Cleveland, Ohio, 44135
(216) 433-2220 VOICE; (216) 433-6106 FAX; hillard@grc.nasa.gov

ABSTRACT

Flight 4A was an especially critical mission for the International Space Station (ISS). For the first time, the high voltage solar arrays generated significant amounts of power and long predicted environmental interactions (high negative floating potential and concomitant dielectric charging) became serious concerns. Furthermore, the same flight saw the Plasma Contacting Unit (PCU) deployed and put into operation to mitigate and control these effects. The ISS program office has recognized the critical need to verify, by direct measurement, that ISS does not charge to unacceptable levels. A Floating Potential Probe (FPP) was therefore deployed on ISS to measure ISS floating potential relative to the surrounding plasma and to measure relevant plasma parameters.

The primary objective of FPP is to verify that ISS floating potential does not exceed the specified level of 40 volts with respect to the ambient. Since it is expected that in normal operations the PCU will maintain ISS within this specification, it is equivalent to say that the objective of FPP is to monitor the functionality of the PCU.

In this paper, we present a top-level overview of the design and testing of the ISS FPP. In a separate paper, the operations and results obtained so far by the FPP will be presented.

INTRODUCTION

It has been clearly understood for some time (refs. 1,2) that the International Space Station (ISS)', by virtue of its high voltage (160 V) primary power generation system, will have important interactions with the ambient plasma in which it orbits. For instance, the negative grounding scheme of its solar arrays would cause the entire ISS structure to act as an ambient ion collector to compensate for the electrons collected by its more positive solar arrays. Models have shown that, in the absence of any mitigation, ISS structure would float at electrical potentials 130-140 V negative of its surrounding plasma (ref. 3). These potentials are far greater than those that could be stood off by the anodized aluminum surfaces on ISS (ref. 4), so that ISS would arc due to dielectric breakdown. These arcs could have consequences ranging from a steady degradation of ISS surface thermal properties to possibly life threatening currents flowing through an astronaut's space suit (ref. 5). In order to control the ISS "floating potential," a pair of Plasma Contacting Units (PCU) have been installed near the ISS structure midpoint, and have begun operating (ref. 6). By emitting a highly conductive xenon plasma, these PCUs can efficiently emit electrons collected by the solar arrays, and thus keep the ISS structure at nearly the same potential as its surrounding plasma, so-called "plasma ground." Proper PCU operations have been shown in ground-based plasma testing to tightly control structure potentials. On-orbit, PCU emission currents are monitored to help ascertain PCU health.

However, during flight-PCU acceptance testing early in the year 2000, a peculiar test failure led to uncertainty whether PCU emission currents were always a valid indicator of PCU health. Because of an inadvertent plumbing error, some of the xenon gas flow from one of the flight PCU's was causing currents to flow from the PCU to adjacent surfaces, not through the emitted plasma. Thus, while PCU "emission" currents were within specifications, the PCU was not "clamping" its floating potential within the specified range. That is, one type of abnormal PCU operation was found for which the emission current was not a valid diagnostic. Of course, for the flight PCU, the problem was corrected, and it was flown and operates to this day. However, it was clear that in order to guarantee proper PCU potential clamping, a direct measure of the ISS floating potential with respect to its surrounding plasma would be required.

PROJECT HISTORY

In March, 2000, the ISS program office asked for clarification of the risks involved in delaying or suspending operations of the PCU. The program office felt that it did not have sufficient understanding of the risk to prioritize the instrument during early phases of power system build when competition for resources would be intense.

To address these concerns, four tiger teams were constituted, funded, and tasked with a top to bottom review of plasma interactions issues resulting from operation of the high voltage solar array-based power system. This activity progressed through the summer and fall of 2000. Extensive testing was performed at the Glenn Research Center (GRC) and the Marshall Spaceflight Center (MSFC) on a variety of ISS materials and the damage that would result from sputtering and other interactions was quantified. This program showed that failure to operate the PCU could result in sufficient damage to thermal control coatings to render ISS uninhabitable in from six months to a year.

Two major Technical Interchange Meetings were held with the ISS program office, in May at MSFC and in June at GRC. As an appreciation of the nature and magnitude of the charging threat developed within the ISS program office, it quickly became apparent that the immediate concern was not for degradation of structural surfaces but for flight crew safety. In particular, modeling and testing led to the conclusion that the initial solar wing deployment, scheduled for flight 4A, would produce sufficient power to charge the existing structure to the 140 volt level, were the PCU to not operate. Such voltages represent a clear threat to astronaut safety during the extravehicular activity (EVA) involved in ISS assembly. In response, the program office requested that a floating potential monitor be flown on flight 4A, scheduled for late November 2000.

While the desirability of such a device has been long recognized, it has been assumed that time precluded such an approach. Indeed, it is generally thought to be impossible for an instrument intended to be part of the ISS on-board monitoring capability to proceed from concept to flight in less than two years. Nonetheless, the request by ISS senior management to do so in less than six months was taken up with GRC as lead. The effort was constituted and funded by ISS in late June under the title Floating Potential Probe (FPP).

The project was structured as two parallel efforts, one technical to produce a suitable device and the other, the more difficult of the two, a program effort to deal with the extensive and complicated approval path needed to satisfy ISS requirements. The technical effort was led by the authors while the program team eventually involved several dozen people drawn from the GRC Space Directorate.

To produce an instrument in such short time, two key decisions were made. First, it was immediately recognized that the schedule did not allow for design and qualification of hardware. The flight unit would therefore have to be assembled from existing flight-qualified subsystems.

Second, it was decided that assembly of the device would be contracted to a small company that specialized in producing instruments of similar size and capability. Design_Net engineering, led by Gerry Murphy was selected. Murphy was formerly the head of the environmental interactions group at JPL and was the original designer of the unit that flew on SAMPIE. The effort would eventually involve all 12 employees of the firm.

The Dynacs Engineering group at GRC functioned as the systems integrator. GRC provided program management and performed qualification and acceptance testing on the delivered FPP, and shipped it to the Kennedy Space Center for integration onto the Space Shuttle. Astronauts deployed FPP on ISS on December 7, 2000, and data was first obtained from the probes on the following day.

In figure 1 the FPP may be seen as it appeared after ground-testing. The gold-color of the main "crate" is due to atomic oxygen-protected kapton, used for on-orbit thermal control. The two probes themselves (5 centimeters in diameter and on the ends of booms) may be seen extending from the face of the crate. The two solar arrays are also on booms, extending from the sides of the crate. The wireless communication antenna is a conical shape mounted on one side of the crate. GRC engineers specified the peculiar solar array orientations to optimize power generation from the non-tracking arrays during normal ISS flight attitudes. Design_Net developed the booms and their locking mechanisms to make construction on-orbit by the astronauts as easy as possible, consistent with stiffness and strength requirements.

FPP DESIGN

With the project underway, there were several constraints that immediately became clear. First, the device must be sufficiently small and light that it could be stowed on the shuttle in a standard locker and easily deployed by the flight crew. Second, it would need to be as autonomous as possible with respect to power and communications rather than depending on ISS systems which, at the early build stage, might not be available or might be impacted by FPP operation. The major subsystems are described below.

Sensors

Hardware from the Solar Array Module Plasma Interactions Experiment (SAMPIE) formed the backbone of the device (ref. 7). SAMPIE's combined Langmuir probe and floating potential monitor, which had been maintained in storage since the flight, were accordingly removed and made available.

This instrument, flown in March 1994 by Ferguson and Hillard, measures basic plasma properties as well as the floating potential of the structure to which it is attached. The device consists of two probes and a control unit. The probes are 5 centimeter spheres mounted on 30-inch masts.

The Langmuir probe sweeps from +10V to -5V in 200 steps, measuring current at each point. Each data point requires .1 second for a total of 20 seconds per sweep. Data is downlinked and analyzed for electron density and temperature using an algorithm developed for SAMPIE (ref. 8). The V-body probe measures the potential difference between the 5 centimeter sphere, assumed to be at plasma ground, and the hardware ground for FPP, assumed to be at ISS structure potential. It has an operation range from 0 volts to negative 150 volts. These reading are also taken at .1 second resolution. Experience with SAMPIE indicated that such resolution, while producing very large quantities of data, is important for resolving the effects of transient events such a thruster firing or docking of an orbiter to ISS.

Power

The requirement that FPP be self-powered, rather than relying on ISS power, had several important implications. First, it resulted in an instrument that was not subject to the inevitable interruptions that would result from depending on a power system that was itself in the early stages of assembly. Since FPP is not a high priority for ISS power, which is in short supply at best, power might not be available even if all ISS systems were working. At the same time, this requirement complicated the design since we had to provide a solar array, suitable battery, and charging subsystem rather than just "plugging it in" to the ISS.

The power source for FPP is built around two small solar arrays, both of ISS design. Originally built for GRC for Space Station research, they have been in storage for the past several years. Each array has 16 solar cells in a 4x4 configuration wired as a single series string. Each array produces approximately 270 watts of power at peak.

The arrays are mounted on FPP in such an orientation that one of them is optimal for each of the two most common flight modes of ISS.

The power system uses a battery to provide power during eclipse. An extensive search on NASA's inventory for existing flight-qualified batteries determined that a nearly optimal unit already existed in the form the battery pack designed to operate the top-mounted light on an astronaut's space suit. These batteries are Nickel Metal Hydride with a capacity of approximately 60 Watt-hours.

Communications

Data is telemetered to the ISS Unity Node through a slightly modified WIS (Wireless Instrumentation System). This device, which has flown successfully several times on the Space Shuttle, was built and supplied by Invocon Corp.

In its normal operational mode, the WIS is a compact, battery operated transceiver that operates in the 920-940 MHz range with digital spread spectrum and transmits directly to the docked orbiter. In its modified form, the WIS uses power

from the FPP and communicates with the Space Station Computer in the Unity Node via an external antenna on the outside of the node.

Controller

FPP is controlled by a space-qualified UT131 Embedded Controller Card from UTMC Corporation. This card, which has flown on FalconSat-1 and has been selected for several other ISS applications uses an on-board 16-bit, 16MHz microprocessor. It offers 14 bit A/D resolution with a sample rate of 11 microseconds, 32 analog inputs, and 64K bytes each of user programmed PROM and on-board SRAM. It is rad-hard to 50K rads (Si) as tested by MIL-STD-883. The board has a form factor of 14.6 x 14.6 centimeters and a mass when fully populated of .313 Kg.

GROUND TESTING

Acceptance testing was performed at GRC and included such standard tests as vibration and thermal vacuum. The test of real interest, however, was plasma chamber operation designed to verify the unit's accuracy in measuring plasma parameters and floating potential. The unit was tested in the Plasma Interactions Facility (PIF) at GRC.

The chamber used is approximately two meters in diameter and two meters long. It is capable of providing a high vacuum better than 10^{-5} Pa. It is typically used with a hollow cathode plasma source that results in a background pressure of 10^{-3} Pa of xenon with an electron density of $10^{12}/m^3$.

Testing of the FPP Langmuir probe was a matter of comparing FPP results with those of stand-alone Langmuir probes. Figures 2 and 3 show this comparison. Electron density generally agreed to better than 50% while temperature was somewhat more variable.

The key test was the ability of FPP to accurately measure floating potential. A series of voltages were applied to the unit's structure and small corrections made for cable capacitance. This "applied" voltage is compared to the FPP measurement in figure 4. As can be seen, agreement is within 1 or 2 % at all voltages. In the figure, the solid line has a slope of 1, representing almost perfect agreement and the dashed line is a regression fit. Regression coefficients show that the agreement is excellent.

CONCLUSIONS

This project clearly demonstrated that it is possible to design and deploy instrumentation on ISS even in the very small time frame of 5 months. Doing so required a high degree of collaboration between government and industry with each partner doing what it does best. Since its deployment, FPP has had an excellent record of on-orbit performance, which is detailed in a companion paper.

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Figure 1 - FPP fully assembled for preflight testing at Cape Canaveral.

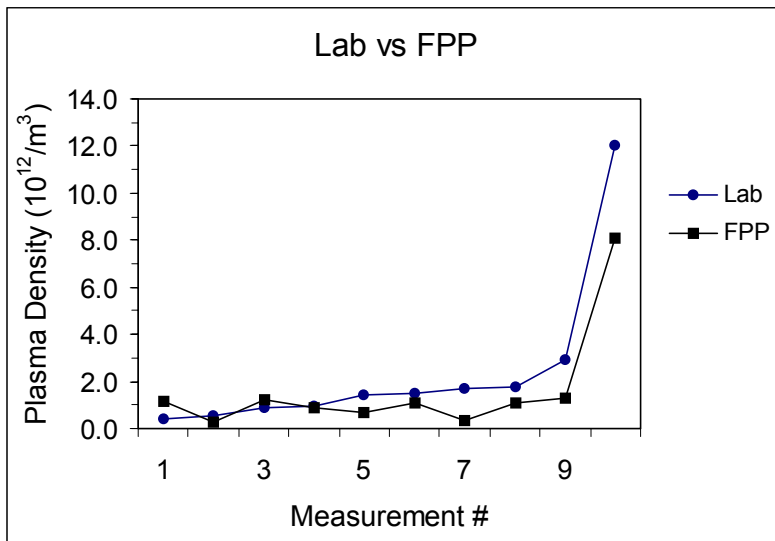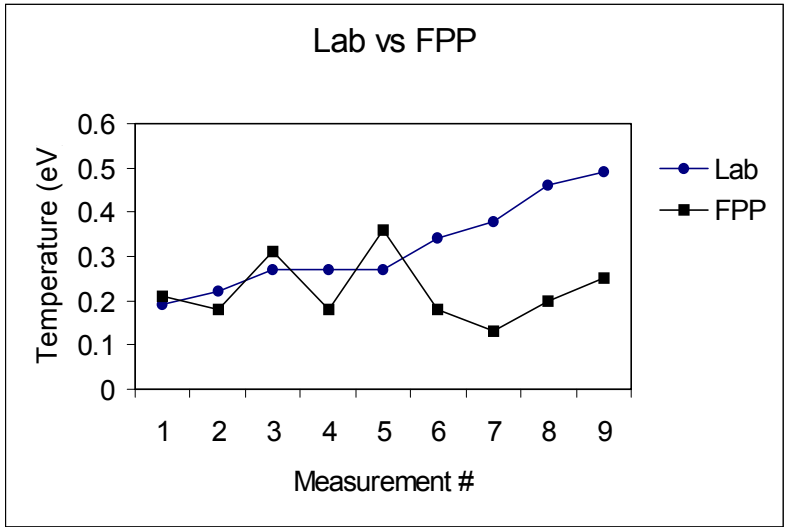**Figure 2 - Comparison of electron density**
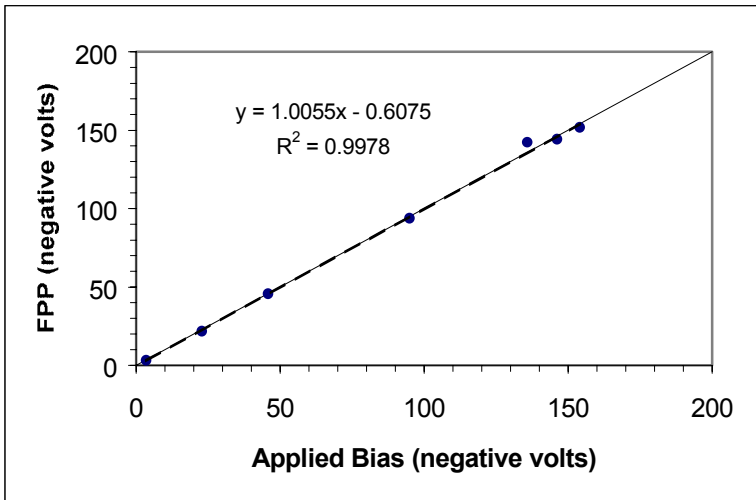
Figure 3 - Comparison of electron temperature

Figure 4 - Comparison of floating potential