THE SOLAR ARRAY MODULE PLASMA INTERACTIONS EXPERIMENT (SAMPIE): Science and Technology Objectives

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ABSTRACT

The Solar Array Module Plasma Interactions Experiment (SAMPIE) is an approved NASA shuttle space flight experiment to be launched in July 1993. The SAMPIE experiment is designed to investigate the interaction of high voltage space power systems with ionospheric plasma. To study the behavior of solar cells, a number of cell coupons, representing technologies of current interest, will be biased to high voltages to characterize both negative potential arcing and positive potential current collection. Additionally, various theories of arc suppression will be tested by including several specially modified cell coupons. Finally, SAMPIE will include experiments to study the basic nature of these interactions. This paper describes the rationale for a space flight experiment, the measurements to be made, the significance of the expected results, and the current design status of the flight hardware.

BACKGROUND

Traditionally, space power systems in Low Earth Orbit (LEO) have operated at low voltages and have not suffered from the effects of plasma interactions. High power systems now under development for space applications will operate at high end-to-end voltages in order to minimize array current. The emergence of such systems is motivated primarily by a desire to save weight. Since the resistance of the necessary cabling is a strongly decreasing function of mass per unit length and cable losses are proportional to current squared, it is desirable to operate at high voltages and low currents. A further consideration is the reduced effect of magnetic interactions (torque and drag) that will follow from low current operation.

While high voltage systems are clearly desirable to the power system designer, they suffer the drawback of interacting with the ionospheric plasma (1,2) in two different ways. First, conducting surfaces whose electrical potential is highly negative with respect to the plasma undergo breakdown and arcing. Such arcing not only damages the material but results in current disruptions, significant electromagnetic interference (EMI), and large discontinuous changes in the array potential. For arrays using traditional silver-coated interconnects, a threshold potential for arcing of about -230 volts relative to the plasma is believed (3) to exist. There are theoretical arguments (4) supported by limited ground test results (5) that different metals will arc at different thresholds. Since new solar cell designs are emerging using copper traces, it is important to determine arcing thresholds, arc rates, and arc strengths for a variety of materials exposed to space plasma.

For solar arrays or other surfaces which are biased positive with respect to the plasma, a second effect occurs. Such surfaces collect electron current from the plasma resulting in a parasitic loss to the power system. Since the mass of electrons is much less than ions, the magnitude of current collection is much greater for surfaces with positive bias. At bias potentials greater than about 200 volts, sheath formation causes the entire surrounding surface, normally an insulator, to behave as if it were a conductor. This effect, called "snapover," results in large current collection even from a very small exposed area. Besides producing a power loss, this current will significantly affect the potentials at which different parts of the array will "float." Depending on the way the power system is grounded, this in turn will affect the equilibrium potentials of various spacecraft surfaces with respect to the plasma.

Two previous flight experiments involving standard silicon arrays, PIX I and PIX II (1,2) have shown many differences between ground tests and behavior in space. For arcing, arc rates in space were quite different and generally higher than in ground tests. For parasitic current collection, the current versus bias voltage curves obtained in space not only differed radically from the ground tests but differed depending on whether the data was taken with the array exposed to spacecraft ram or wake. It is necessary, therefore, that the behavior of various solar cell technologies be established with a suitable in-space test.

In this paper, we have only briefly reviewed the background and justification for SAMPIE since this has been presented previously (6). We will present the status of the design and a discussion of the selected experiments to be done.

OBJECTIVES

The general objective of SAMPIE is to investigate, with a Shuttle-based space flight experiment and relevant ground-based testing, the arcing and current collection behavior of materials and geometries likely to be exposed to LEO plasma on high voltage space power systems. There are seven specific objectives of the SAMPIE experiment:

1. For a selected number of solar cell technologies, determine the arcing threshold and arc rates and strengths. At a minimum, the solar cells selected for flight must include:
    a. A sample array made of traditional silicon solar cells. This will provide a baseline for comparison with past experiments.
    b. A sample array using APSA, the Advanced Photovoltaic Solar Array.
    c. A sample array using current space station solar cell technology.
2. For these sample arrays, determine the plasma current collection characteristics.
3. Propose, demonstrate in ground tests, and fly an arc mitigation strategy; i.e., modifications to standard interconnect design which may significantly improve the arcing threshold.
4. Design simple metal/insulator mockups to allow the dependance of current collection on exposed area to be studied with all other relevant parameters controlled.
5. Design a simple arcing experiment to test the dependance of arcing threshold, arc rates, and arc strengths on the choice of metal with all other relevant parameters controlled.
6. Design, test, and fly simple controlled experiments to study basic phenomena related to arcing and its effects. Added on a space-available basis subject to time and resource constraints, these may include such things as:
    a. Arcing from anodized aluminum using alloys and anodization processes typical of ones being considered for use on large space structures.
    b. Arcing from pinholes in Indium-Tin oxide (ITO) coated conductors or from biased conductors covered with strips of ITO.
    c. Sputtering and degradation of metals or metal covered insulators biased to high negative potential in the atomic oxygen environment of LEO.
7. Measure a basic set of plasma parameters to permit data reduction and analysis. An additional requirement to aid data reduction is to provide timely flight data (such as the Shuttle orientation, and times of thruster firings) relevant to SAMPIE flight conditions.

APPROACH

SAMPIE will consist of a metal box with an experiment plate fixed to the top surface. It will mount directly to the top of a Hitchhiker-M carrier. A power supply will bias the solar cell samples and other experiments to DC voltages as high as +700 volts and -700 volts with respect to shuttle ground. When biased negative, suitable instruments will detect the occurrence of arcing and measure the arc-rate as a function of bias voltage. For both polarities of applied bias, measurements will be made of parasitic current collection versus voltage. Other instruments will measure the degree of solar insolation, plasma electron density and temperature, and monitor the potential of the shuttle with respect to the plasma. Shuttle operational logs will be relied upon for detailed information about the orientation of the experiment with respect to the vehicle's velocity vector as well as times and conditions of thruster firings.

In a simplified description of the experiment, one sample is biased to a particular voltage for a preset time while measuring arcing and current collection data. A set of plasma diagnostics is then taken and the procedure repeated at the other bias voltages until all measurements are completed. Vehicle orientation is critical since ram and wake effects are known to be significant. SAMPIE will request control of the orbiter orientation such that one entire set of measurements is made with the payload bay held in the ram direction and a second set with the bay in the wake.

DESIGN STATUS

Since SAMPIE was originally designed to be deployed on a 15 meter collapsible tube mast of ESA

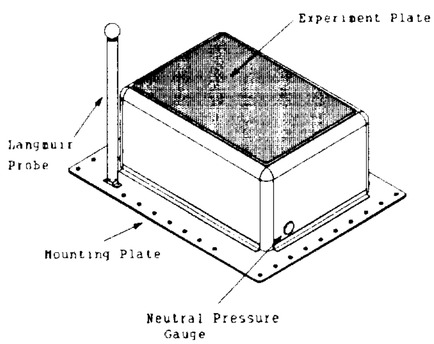

Fig. 1 External view of SAMPIE package

design (6), it has been severely constrained in mass. As a result, although the current baseline is for direct mounting to the Hitchhiker carrier, the package remains quite compact. Figures 1 and 2 show the basic package.

Figure 3 shows the proposed layout of the experiment plate. To meet objectives 1 and 2, which require extensive solar cell testing, a number of cell coupons are provided.

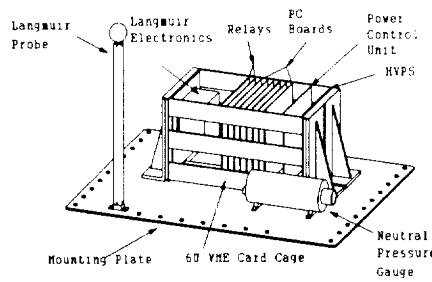

Fig. 2 Internal view of SAMPIE package

a. A baseline for comparison is provided by including a small 9-cell coupon of standard technology silicon 2 cm by 2 cm cells. This is the technology that has been used exclusively in the U.S. space program to date. It was flown on PIX I and PIX II as well as being the subject of extensive ground based testing and will provide a basis for continuity with past results. A second coupon of standard cells is shown surrounded by a metal guardring. this is simply a metal structure which can be biased independently of the cell coupon and is designed to test the effect of a large surrounding solar array. NASCAP/LEO will be used to determine the appropriate bias voltages for each bias applied to the coupon.

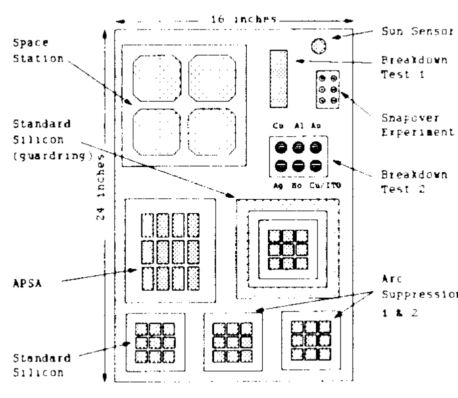

Fig. 3 SAMPIE experiment plate

b. A 4-cell coupon of 8 cm by 8 cm space station cells, having copper interconnects in the back will allow a test of this technology.

c. A 12-cell coupon of 2 cm by 4 cm APSA cells will test the behavior of this relatively new, very thin (60 micron) technology. APSA is normally a flexible blanket mounted in an external frame while the original intent on SAMPIE was to mount the cells directly to the stiff experimental plate. While it is highly likely that the plasma interactions encountered by the cell array will be the same, this point has yet to be proven. Two coupons, one mounted rigidly and the other in the flexible, baseline design, will be subjected to extensive ground testing. If there are clearly no differences, it will be easier to fly the rigidly mounted assembly. If differences are found, every attempt will be made to design a flight-qualifiable mounting scheme for the flexible array segment.

There are several experiments designed to test basic theories of arcing and current collection.

a. The first of the two breakdown tests shown in figure 3 will explore the hypothesis that negative potential arcing is a special case of the classical vacuum arc (7). With geometry and test conditions controlled, only the composition of the metal will be varied. The resulting family of arc rate versus bias voltage curves will give considerable insight into the basic nature of the arcing process. The particular choice of metals is based on current and anticipated importance to space technology.

b. The second breakdown test consists of a single sample of anodized aluminum. There is considerable concern that this material undergoes dielectric breakdown and arcing when biased to high voltages (8). The particular alloy and anodization process are chosen to be identical with structural material currently baselined for Space Station Freedom.

c. To study current collection and snapover, we include six 1-cm diameter copper disks covered with 5 mil kapton. Each has a pinhole in the center with hole sizes tentatively chosen as .1 mm, .3 mm, .5 mm, .7 mm, 1 mm, and 1.5 mm. The resulting family of current versus applied bias curves will be compared with predictions of NASCAP/LEO and other theoretical treatments.

Several arc suppression techniques are under investigation as part of our ground based testing. These generally follow from the work of Katz et. al. (9) on the SPEAR program which showed that inbound ions striking the junction of insulator, metal, and plasma, sometimes called the triple point, result in secondary emission and arcing.

a. The first technique we will test follows from recent NASCAP/LEO (10) modeling done in support of Space Station Freedom. The results indicate that simply extending the cover slides to cover a larger portion of the gap between cells is sufficient to choke off most of the ion current. We will test this idea with specially modified 2 cm by 2 cm silicon cells since space limitations would make a second space station coupon difficult to accommodate.

b. The second technique we will test was developed by Physical Sciences Inc. under a still open SBIR contract (11). This work has shown that a major factor in arcing is ion bombardment of excess adhesive which is inevitably present in the gap between cells. Current plans are for a coupon of silicon 2 cm by 2 cm cells to be sent to PSI, subjected to their newly developed cleaning process, and returned for incorporation into SAMPIE.

SUMMARY

The SAMPIE flight experiment is the first orbited space power system - plasma interaction experiment since PIX II and is by far the most ambitious to date. Besides testing two emerging solar cell technologies, it will explore the viability of several arc suppression techniques. Using controlled experiments, it will provide basic data on arcing and current collection which can be used to validate and extend existing models and theories. SAMPIE will be designed and built in a highly modular way that will have easy reflight capability in mind. To this end, it can serve as a test-bed for future technologies.

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