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THE SOLAR ARRAY MODULE PLASMA INTERACTIONS EXPERIMENT (SAMPIE)
A Shuttle-based Plasma Interactions Experiment

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ABSTRACT

The SAMPIE flight experiment, tentatively scheduled to fly on the OAET-1 shuttle mission in mid 1992, will investigate plasma interactions of high voltage space power systems. Solar cells representing a number of technologies will be biased to high voltage to study both negative potential arcing and positive potential current collection characteristics. Additionally, several idealized metal/insulator mockups will be flown to study the basic nature of these interactions. Originally proposed as a collaboration with the European Space Agency (ESA), SAMPIE is now primarily a NASA effort with the possibility of limited involvement by ESA. This paper briefly describes the rationale for a space experiment as well as the measurements to be made and the significance of the expected results. The current design status of flight hardware is presented.

INTRODUCTION

Traditionally, space power systems have operated at low voltages and have not suffered from the effects of plasma interactions. High power systems now being developed 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 since 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 obviously desirable from the standpoint of the power system designer, they suffer the drawback of interacting with the ionospheric plasma (Grier and Stevens, 1978 and Grier, 1983) in two different ways. Conducting surfaces which are at a high negative bias with respect to the plasma undergo arcing which causes 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 (Ferguson, 1986) to exist. There are theoretical reasons (Jongeward et. al., 1985) and limited ground test results (Snyder, 1986) to believe 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. In addition to producing a power loss, this current will significantly effect the potentials at which different parts of the array will "float". Depending on the way the power system is grounded, this in turn will effect 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 (Grier and Stevens, 1978 and Grier, 1983), have shown many differences between ground tests and behavior in space. For arcing, arc rates in space were quite different and generally larger 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 (Ferguson, to be published). We will present the current status of the design and a discussion of the selected experiments to be done.

OBJECTIVES

There are six basic objectives of the SAMPIE experiment:

1. For a selected number of solar cell technologies, determine the arcing threshold as well as arc rates and strengths.

2. For these solar cells, 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.

6. Measure a basic set of plasma parameters to permit data reduction and analysis.

APPROACH

SAMPIE will consist of a metal box with an experiment plate fixed to the top surface. It will mount directly to the Hitchhiker-M carrier and will have a suitable adapter to permit either top or side mounting. 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 operations 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.

A simplified description of the experiment is to bias one solar cell sample 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 is repeated at the other bias voltages until all measurements have been made. 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 design (Ferguson, to be published), 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. Figure 1 shows several views of the basic package. The top mounted experiment plate overhangs the box on three sides, allowing the langmuir probe to be attached on the back.

Figure 2 shows the proposed layout of the experiment plate. For solar cells, 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 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. 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.

A breakdown test will explore the hypothesis that negative potential arcing is a special case of the classical vacuum arc (Hillard, to be published). With geometry and test conditions controlled, only the composition of the metal varies. To study snapover, we include 6 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.

A number of arc suppression techniques are under investigation as part of our ground based testing. These all follow from the work of Katz et. al. on the SPEAR program which showed that inbound ions striking the junction of insulator, metal, and plasma, sometimes called the triple point, resulted in secondary emission and arcing. A bushing employing a set of guard rings (Katz and Cooper) to collect inbound ions was able to prevent arcing in the SPEAR tests. Figure 3 shows three possible ways to exploit this finding.

Figure 3a shows the basic model of a solar cell biased to a high negative potential in a plasma environment. Inbound ions are free to strike the triple points, producing secondary electron emission which leads to breakdown. Figure 3b shows a straightforward attempt to collect inbound ions before they reach the triple points by using a small conducting rod which protrudes from each interconnect. In figure 3c, a conducting dielectric, possibly ITO, covers the critical junctions. Figure 3d shows that simply extending the coverslides to the maximum consistent with mechanical constraints may be sufficient to control the flow on inbound ions.

All of these techniques will be pursued in the ground based phase of the project. If successful, one or more of them will be flown.

SUMMARY

The SAMPIE flight experiment is the first space power system - plasma interaction experiment since PIX II and is by far the most ambitious to date. In addition to 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 compared to existing 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 solar cell technologies.

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Katz and Cooper, U.S. patent 4835841

Snyder, D.B. 1986, Private Communication

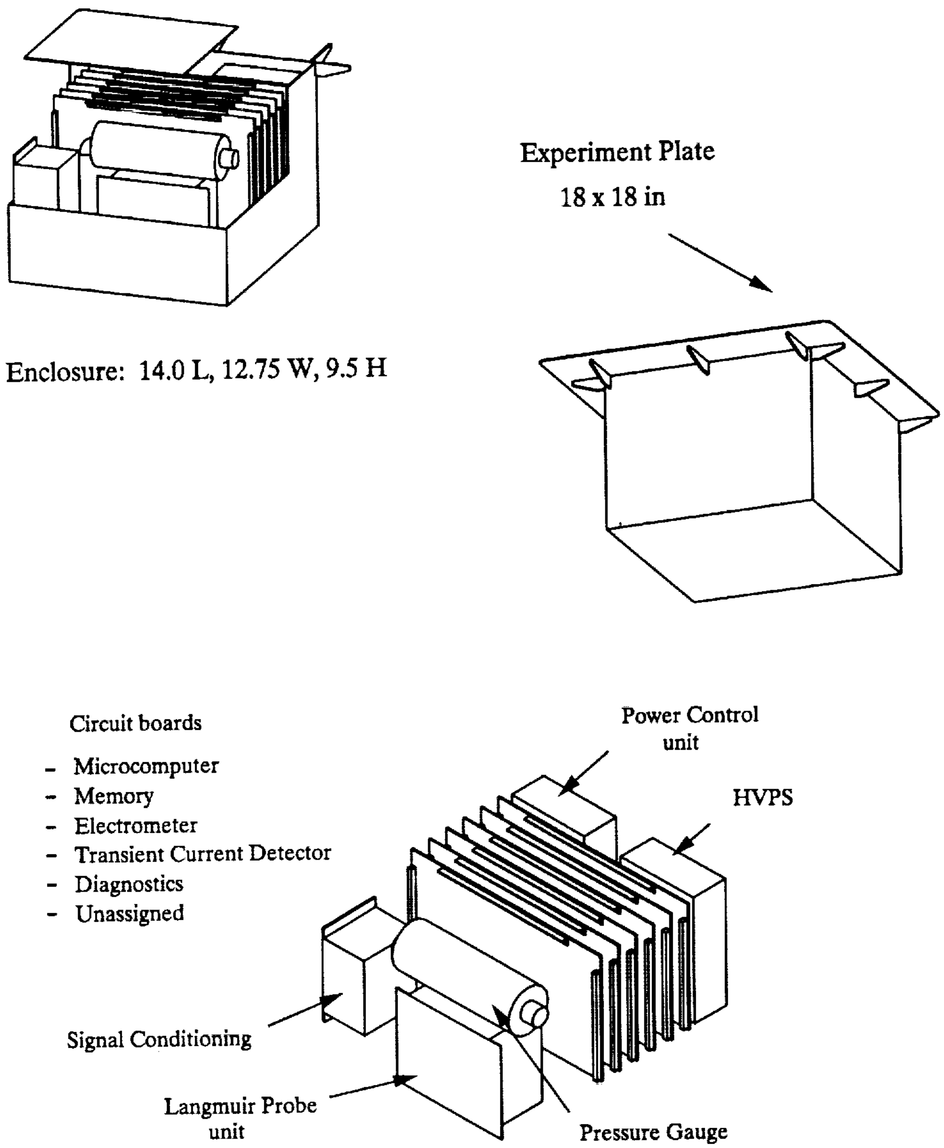

Figure 1 - Current design of experiment package

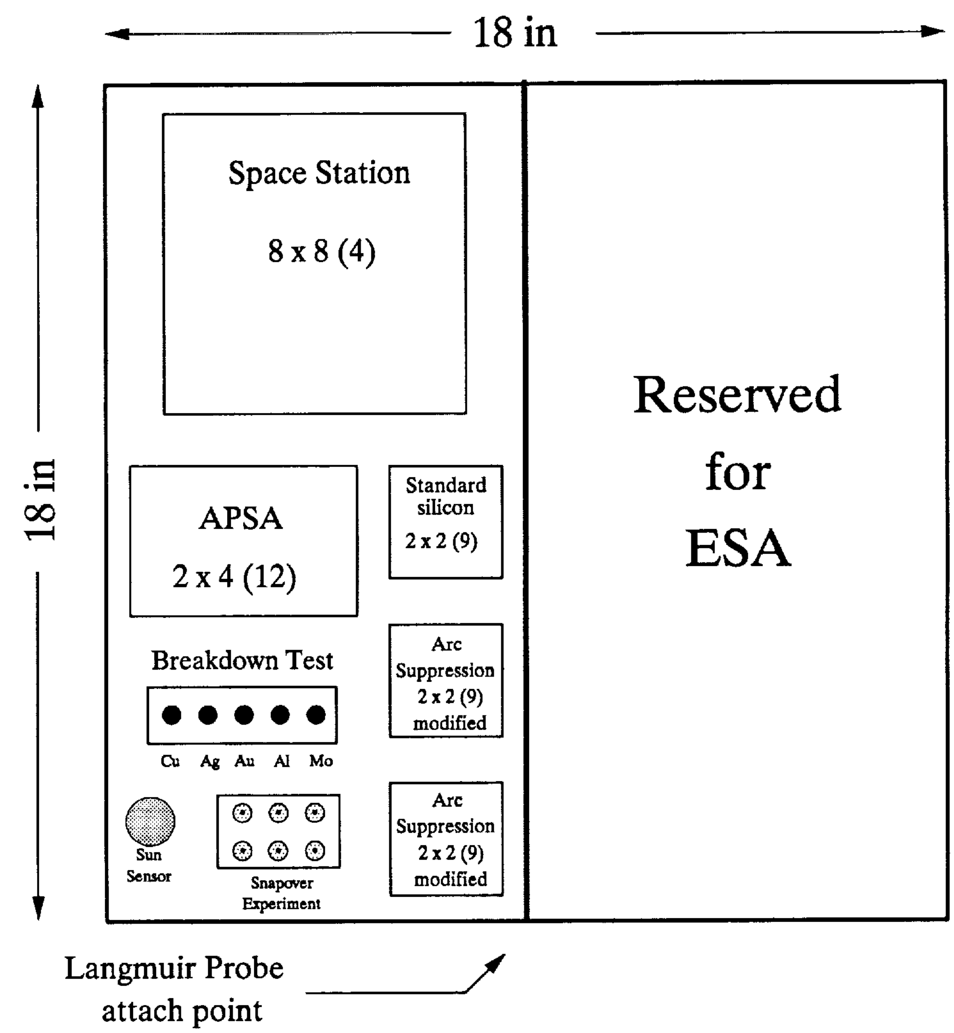

Figure 2 - layout of experiment plate
(solar cell dimensions in cm)

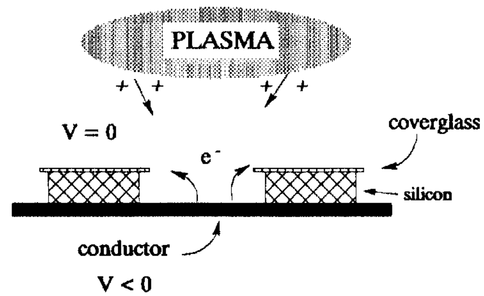

Figure 3a - schematic representation of standard solar cell model

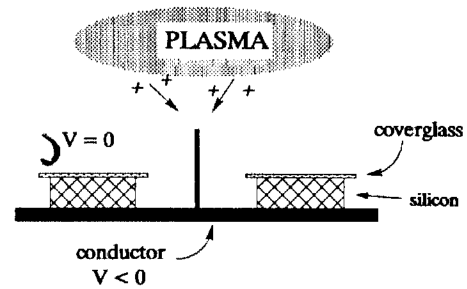

Figure 3b - schematic representation of possible "lightning rod" modification

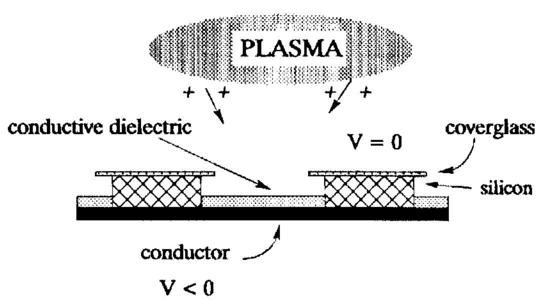

Figure 3c - schematic representation of possible "dielectric coating" modification

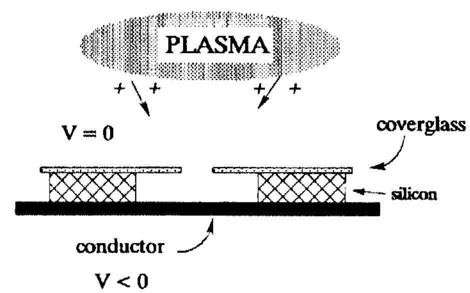

Figure 3d - schematic representation of possible "extended coverglass" modification