

**N95-20529**

PRELIMINARY RESULTS FROM THE FLIGHT OF THE SOLAR ARRAY MODULE  
PLASMA INTERACTIONS EXPERIMENT (SAMPIE)

Dale C. Ferguson and G. Barry Hillard  
NASA Lewis Research Center  
Cleveland, Ohio

SAMPIE, the Solar Array Module Plasma Interactions Experiment, flew in the Space Shuttle Columbia payload bay as part of the OAST-2 mission on STS-62, March, 1994. SAMPIE biased samples of solar arrays and space power materials to varying potentials with respect to the surrounding space plasma, and recorded the plasma currents collected and the arcs which occurred, along with a set of plasma diagnostics data. A large set of high quality data was obtained on the behavior of solar arrays and space power materials in the space environment. This paper is the first report on the data SAMPIE telemetered to the ground during the mission. It will be seen that the flight data promise to help determine arcing thresholds, snapover potentials and floating potentials for arrays and spacecraft in LEO.

### INTRODUCTION

Solar cells in low Earth orbit (LEO) environments have been shown to arc into the surrounding plasma when they are at a potential highly negative of the plasma (Ref. 1) and to collect anomalously large currents from the plasma (to "snapover") when at high positive potentials (Ref. 2). The space flight experiments PIX and PIX II showed that these phenomena are not confined to a laboratory environment, but occur naturally in space plasmas. Using data from these experiments and ground tests, Ferguson (Ref. 3) derived a threshold potential for plasma arcing from standard silicon solar cells, which has been the object of several theoretical treatments (Refs. 4 through 6). Based partly on these treatments, several means of mitigating the arcing phenomenon have been proposed (see Ref. 7). In addition, it has been shown that the currents collected by high voltage array strings in LEO will force negatively grounded power systems to "float" at high negative potentials relative to the plasma, where solar array arcing and/or breakdown of dielectric coatings may occur, causing possible power disruptions, EMI, and surface damage (Ref. 8). To prevent such occurrences, a plasma contacting device (a plasma contactor, or "PC") has been baselined for the International Space Station (ISSA), and operates by actively controlling the ISSA floating potential. This complex and expensive solution to a simple problem makes one desire simpler, cheaper methods of predicting and/or controlling spacecraft floating potentials or arcing thresholds. SAMPIE was flown to investigate the arcing and current collection phenomena in space, to enable the understanding and mitigation of arcing and other undesirable plasma effects.

### SAMPIE

Figure 1 shows the electronics box and sample tray of the SAMPIE experiment. It was mounted on the top of a Hitchhiker cross-bay experiment carrier in the payload bay of the Space Shuttle Columbia. Inside this box (Figure 2) were the electronics that controlled the experiments, biased samples on the sample tray to high potentials, measured, stored and telemetered the resulting data, and measured the surrounding plasma conditions. On the side of another Hitchhiker attachment plate were two plasma diagnostic probes (a Langmuir probe and a vehicle potential, "V-Body", probe) to determine the plasma conditions during the biasing experiments. A pressure gauge monitored the payload bay pressure at one end of the electronics box.

Figure 3 shows a blowup of the electronics box and sample tray (experiment plate) assembly. On the sample tray were the samples which were biased in the LEO plasma conditions (Fig. 4). In all, there were 37 different experiment configurations which were tested in LEO. Two high voltage power supplies (HVPS-1 and HVPS-2) in the electronics box biased the experiments to predetermined voltages relative to the Orbiter. An electrometer in the HVPS-1 circuit measured the currents collected, and transient current detectors on both power supply circuits counted the arcs that occurred, on the biased samples. Both ion and electron collection currents were measured at the appropriate biases. The maximum biases attained were -600 V and + 300 V, relative to the Shuttle chassis. Thanks to the large collecting area of the Shuttle main engine nozzles, Columbia stayed within a few volts of the surrounding plasma during all of the bias and plasma conditions encountered.

Of interest to the Space Photovoltaic Power community were several solar array experiments. A twelve cell series coupon of the Advanced Photovoltaic Solar Array (APSA) was flown. A four cell string of Space Station technology cells were also flown. As the backs of these ordinarily flexible arrays are covered with Kapton, precluding significant plasma interactions from the array backs in LEO, the array backs were attached to the experiment plate by adhesive. These arrays were loaded to near their maximum power points by load resistors. In addition, three separate concentric strings of standard 2x2 cm silicon solar cells (similar to those flown on PIX and PIX II) were flown to serve as a control, and to investigate the dependence of current collection on the presence of surrounding solar cells.

Three sets of modified quarter-cells of Space Station design were flown to investigate the dependence of arc rate and current collection on solar cell parameters such as the presence or absence of adhesive on cell edges, the degree of adhesive coverage, and the overhang of cell coverslides past the cell edges. Previous work by many authors (Refs. 9 through 11) had predicted that by varying these parameters, cell arcing and/or current collection would be modified or prevented. To determine the dependence of arcing on exposed conductor properties, samples of pure metals were flown, with insulator strips or adjacent ground rods to encourage arcing. Since the floating potential of ISSA will depend to a great degree on the possibility of current collection by its radiator thermal control paint (Z-93), which had been shown by Hillard to be non-conductive in ground plasma tests (Ref. 12), a small sample of Z-93 was also flown. To investigate the arcing behavior of the ISSA structural material (anodized aluminum), a sample prepared to ISSA truss specifications was flown. The snapover effect, where insulators surrounding exposed conductors at high positive potentials start collecting currents as if they were conductors, was investigated by biasing conductors behind insulation pinholes of various sizes. Finally, a sun sensor on the sample tray confirmed the vehicle attitude. A more complete description of SAMPIE's experiments may be found in Ref. 13.

Preliminary data were telemetered back through the OAST-2 payload operations control center at Goddard Space Flight Center. During the experiment, an anomaly with the HVPS-1 circuit midway through the 37 hours of scheduled data-taking necessitated reconsideration of the experiment timeline, and new instructions were telemetered up to SAMPIE on orbit. In all, about 62 hours of data were obtained, stored on-board, and recovered after Columbia returned to Earth. Data were taken in the bay-to-earth, bay-to-ram, and bay-to-wake orientations. Initial inspection of the data show that they are surprisingly noise-free, and easily constitute the largest and best set of data on the interactions of solar arrays and space power materials with the LEO environment ever obtained.

## PRELIMINARY RESULTS

Inspection of Figure 5 shows just how noise-free the SAMPIE data are. These curves of data on the electron collection of the APSA and SS (Space Station) arrays in the bay-to-earth orientation represent

comparison of not just the two array types, but also of the maximum and minimum measured currents at each bias step. Because they were obtained at plasma densities that varied by as much as a factor of ten, and because the Langmuir probe data have not yet been reduced, the different array types can't be naively directly compared or calibrated, but it is clear that the APSA array, with a smaller array area, collects significantly more current than does the array of Space Station cells at all potentials less than about +100 volts. Both arrays go into snapover at voltages between +200 V and +300 V, and at +300 V nearly the entire kapton-covered surface of the sample tray is snapped over in both cases. In Figure 6, the increase in APSA electron current at comparable voltages may be due to increased ram collection or to increased plasma densities. When the Langmuir probe data are reduced, the answer will be known.

Figure 7 shows the electron current collected in the ram condition, near the time of maximum orbital plasma density, for the Space Station array. It is believed that the plasma densities shown in this figure are overestimates by about a factor of 3.6. These data show that the Space Station cells, despite their lack of exposed interconnectors, can collect significant currents from the plasma, and thus influence the Space Station floating potential. It has been estimated that to prevent large negative potential excursions on ISSA, an exposed conducting area of 1000 to 2000 square meters would be required, were the plasma contactor not baselined for ISSA. The data also support the conclusion that the maximum current presently being considered for ISSA PC operation (10 A) will be sufficient to control the ISSA potential at all times. Space Station cells that have been modified to have varying degrees of coverslide overhang do indeed collect different amounts of current, as shown in Figure 8. Preliminary looks at the data seem to imply that a coverslide overhang of 11 mils would reduce the electron current collection of the ISSA arrays by at least an order of magnitude, reducing the need for a plasma contactor. Similar effects may be obtained by ensuring complete coverage of the cell edges with adhesive, although this paradoxically may increase their arc rates (Ref. 7). Reduction of the SAMPIE data on arcing of cells without exposed adhesive may help settle this question. Comparison of the data with those taken in ground plasma tests (Ref. 14) will also be instructive.

Figure 9 shows some of the arcing data on the anodized aluminum sample. As is typical of dielectric breakdown, the arc rate shows a strong dependence on the potential (in this case, we have fit the dependence by a power-law). Although these data have been normalized to a standard plasma condition and plate area, absolute rates must await reduction of the Langmuir probe data. It may be possible to determine an arcing threshold for this thickness of anodized aluminum in a plasma by further reduction of the complete data set.

During the SAMPIE arcing experiments, every sample biased to high negative potentials arced at least once, except for a sample of gold nearby a grounded rod. It may be hypothesized that the lack of surface oxides and/or contaminants prevented arcing in this case, although this is still speculation. In proximity to insulating Kapton strips, even gold showed arcs.

In addition to the experiments conducted to further our knowledge of arcing and current collection, SAMPIE also obtained payload bay pressure measurements to aid in the interpretation of the Experimental Investigation of Shuttle Glow (EISG) experiment data. Figure 10 shows some of the pressure data obtained for EISG, including times when the thrusters fired and gas releases took place. These events are clearly seen in the pressure record.

## SUMMARY AND CONCLUSIONS

SAMPIE obtained excellent data on the arcing and current collection characteristics of solar arrays and space power materials in LEO. Further analysis of these data may furnish us with a better

understanding of, and better means to control, arcing on solar arrays and spacecraft in the LEO environment. The result could be better solar array or power system designs, ensuring years of safe and reliable operation in the harsh LEO plasma.

In order to determine the behavior of even newer and more diverse materials and solar arrays in the LEO environment, it is planned to reflly SAMPIE with different samples on the sample tray. This low-cost reflight may be one of our best near-term opportunities to learn more about LEO arcing and current collection behavior.

#### ACKNOWLEDGEMENTS

The authors would like to thank the Office of Advanced Concepts and Technology for footing the bill for SAMPIE. Their foresight and forbearance led to the great success that SAMPIE has become. Our thanks also go to the great SAMPIE team, all the way from technicians to project management, who built SAMPIE and ensured that it would work on-orbit. Like any great team, the watchword for the SAMPIE team was teamwork. Individual egos notwithstanding, the SAMPIE team worked cooperatively and selflessly to see the project through to completion. Thanks to Thomas L. Morton for his fine reduction of the SAMPIE Langmuir probe and modified Space Station cell data. We would also like to acknowledge the contributions of Steven C. Zook, a brilliant young software and electronics engineer who met an untimely death before SAMPIE was completed. We will miss him. Finally, we acknowledge the excellent OAST-2 mission control team at Goddard Space Flight Center. We could not have asked for a more responsive and supportive team during our real-time reprogramming of the SAMPIE timeline.

#### REFERENCES

1. Grier, N.T. (1983). "Plasma Interaction Experiment II: Laboratory and Flight Results," in NASA CP-2359, p. 333, 1985.
2. Gabriel, S.B., Garner, C.E. and Kitamura, S. (1983). "Experimental Measurements of the Plasma Sheath Around Pinhole Defects in a Simulated High-Voltage Solar Array," AIAA Paper 83-0311.
3. Ferguson, D.C. (1986). "The Voltage Threshold for Arcing for Solar Cells in LEO - Flight and Ground Test Results," NASA TM-87259.
4. Jongeward, G.A. et al (1985). "The Role of Unneutralized Surface Ions in Negative Potential Arcing," IEEE Trans. Nucl. Sci., vol. NS-32, no. 6, Dec., pp. 4087-4091.
5. Hastings, D.E., Weyl, G., and Kaufman, D. (1990). "Threshold Voltage for Arcing on Negatively Biased Solar Arrays," J. Spacecraft and Rockets, 27, p. 539.
6. Mong, R.L. (1993). "Arcing Mitigation and Predictions for High Voltage Solar Arrays," Master's Degree Thesis, Massachusetts Institute of Technology.
7. Ferguson, D.C. (1993). "Interactions Between Spacecraft and their Environments," AIAA Paper 93-0705.
8. Ferguson, D.C., Snyder, D.B., and Carruth, R. (1990). Final Report of the Joint Workshop on Evaluation of Impacts of Space Station Freedom Grounding Configurations, NASA LeRC,

August 21, 1990.

9. Upshulte, B.L. et al (1991). "Significant Reduction in Arc Frequency of Negatively Biased Solar Cells: Observations, Diagnostics, and Mitigation Technique(s)," in NASA CP-3121, p. 32-1.
10. Cho, M. and Hastings, D.E. (1991). "Dielectric Charging Processes and Arcing Rates of High Voltage Solar Arrays," J. Spacecraft and Rockets, 28, pp.698-706.
11. Hillard, G.B. and Ferguson, D.C. (1993). "The SAMPIE Flight Experiment Final Technical Requirements Document," NASA TM-106224.
12. Hillard, G.B. (1993). "Experimental Measurement of the Plasma Conductivity of Z93 and Z93P Thermal Control Paint," NASA TM-106284.
13. Hillard, G.B. and Ferguson, D.C. (1993). "The Solar Array Module Plasma Interactions Experiment (SAMPIE): Science and Technology Objectives," J. Spacecraft and Rockets, 30, p. 488.
14. Bozich, R.C. (1994). "Characterization of Solar Cells and Metal Samples in a Plasma Atmosphere Using the SAMPIE Proto-type Model System," Master's Degree Thesis, Cleveland State University.

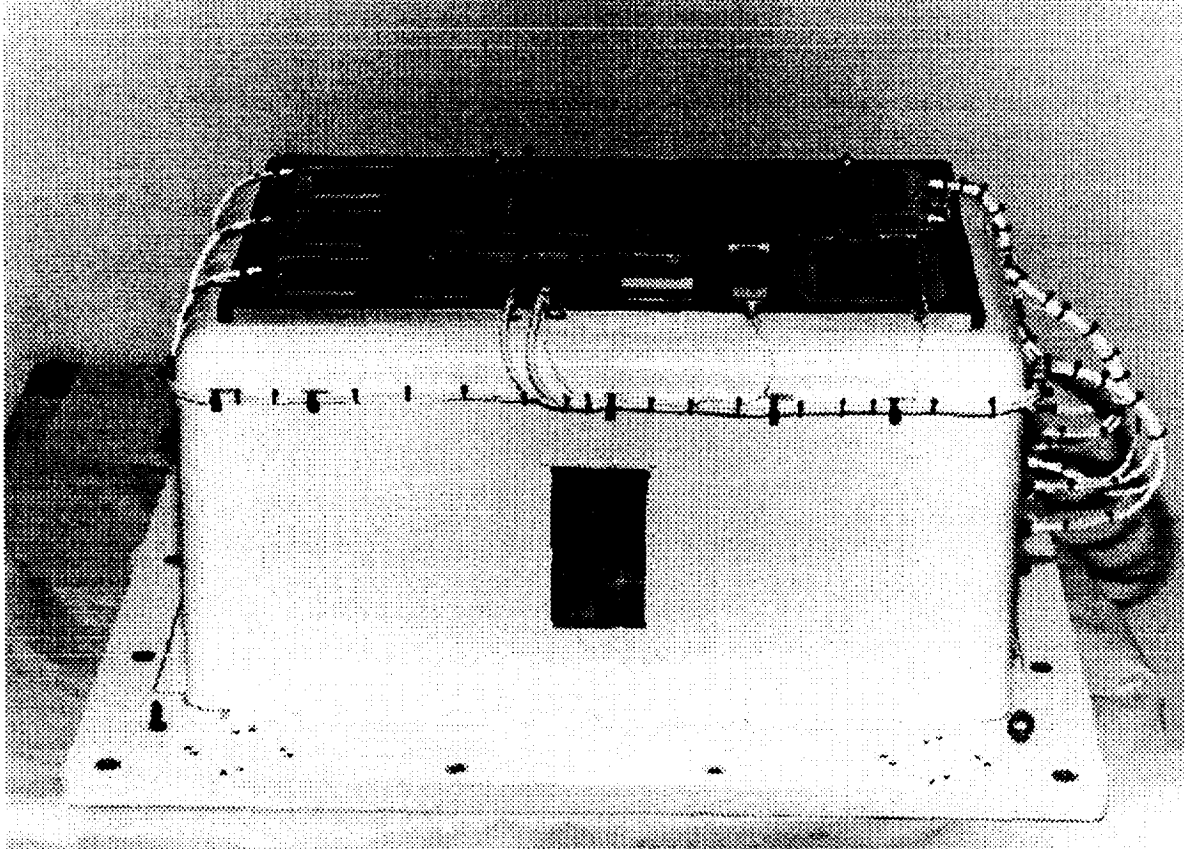


Figure 1. The Solar Array Module Plasma Interactions Experiment (SAMPIE) electronics box and sample tray.

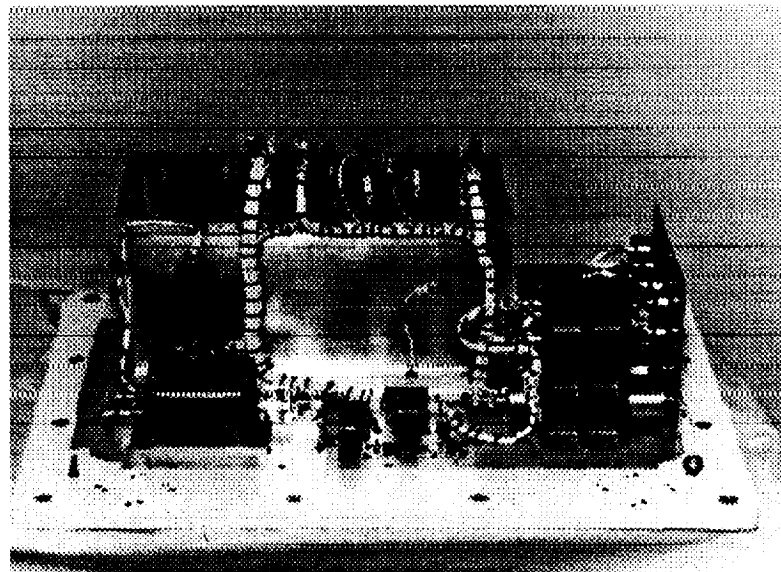


Figure 2. The SAMPIE electronics box card cage and interior components.

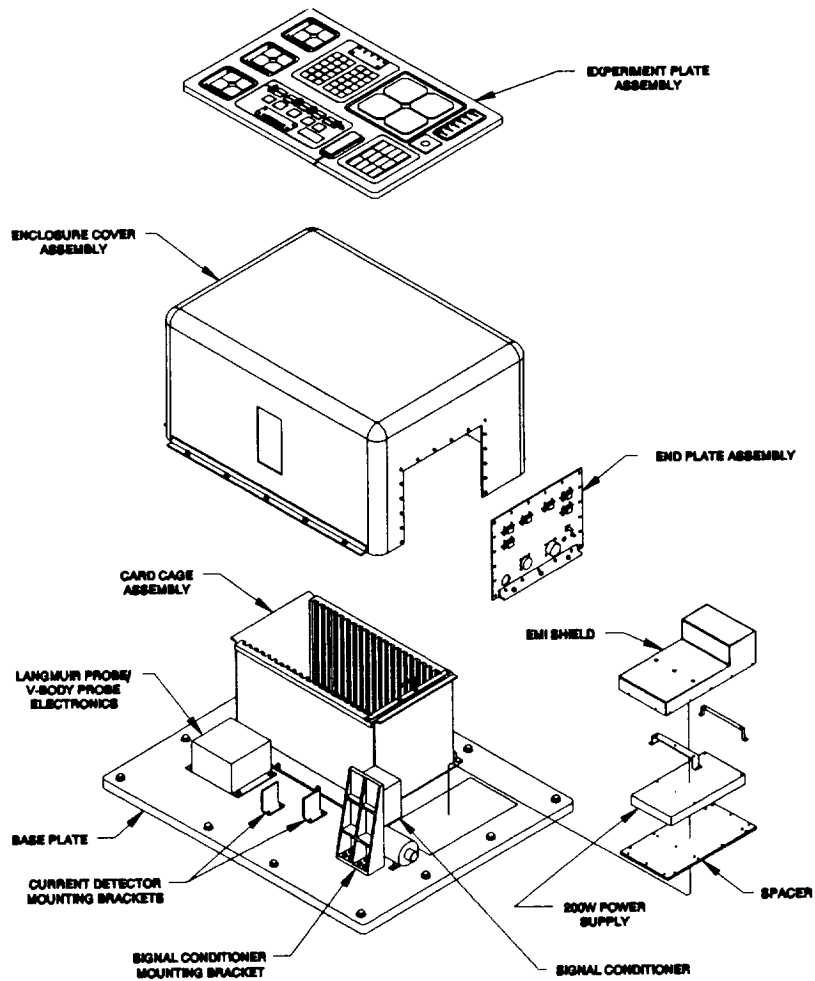


Figure 3. An exploded view of the SAMPIE electronics box and sample tray.

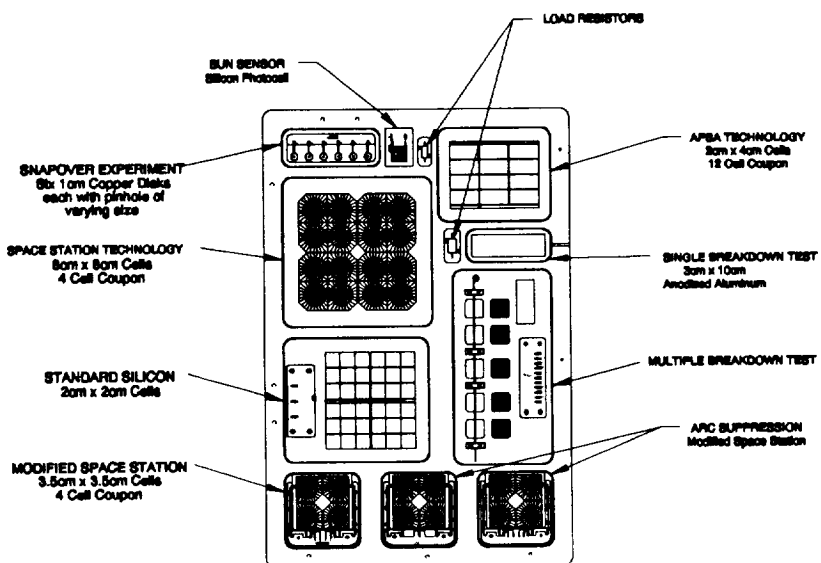


Figure 4. The SAMPIE sample tray.

## APSA and SS Currents, Bay-to-Earth

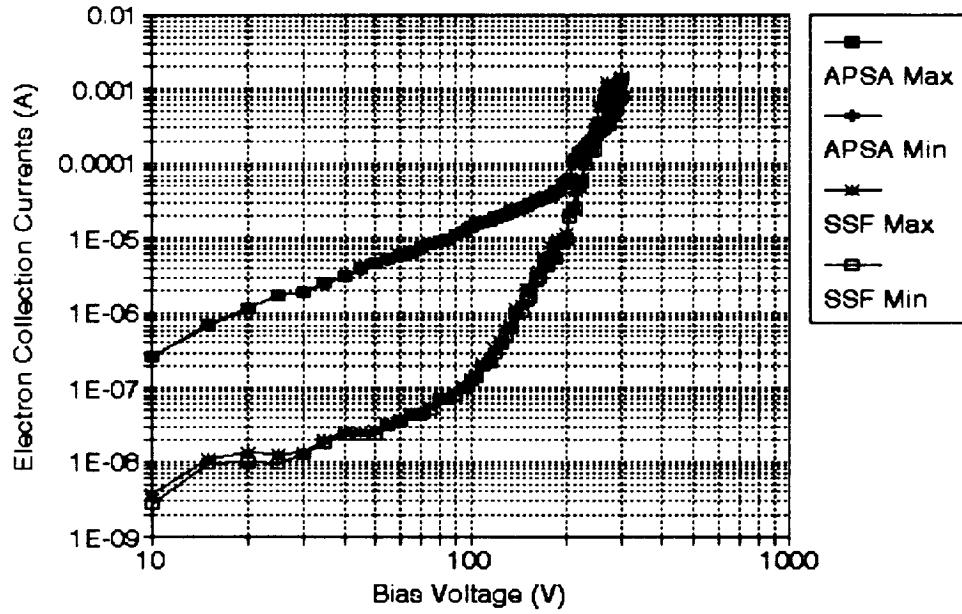


Figure 5. Electron currents collected by the APSA and Space Station arrays in the bay-to-earth orientation.

## APSA Currents, Bay-to-Ram

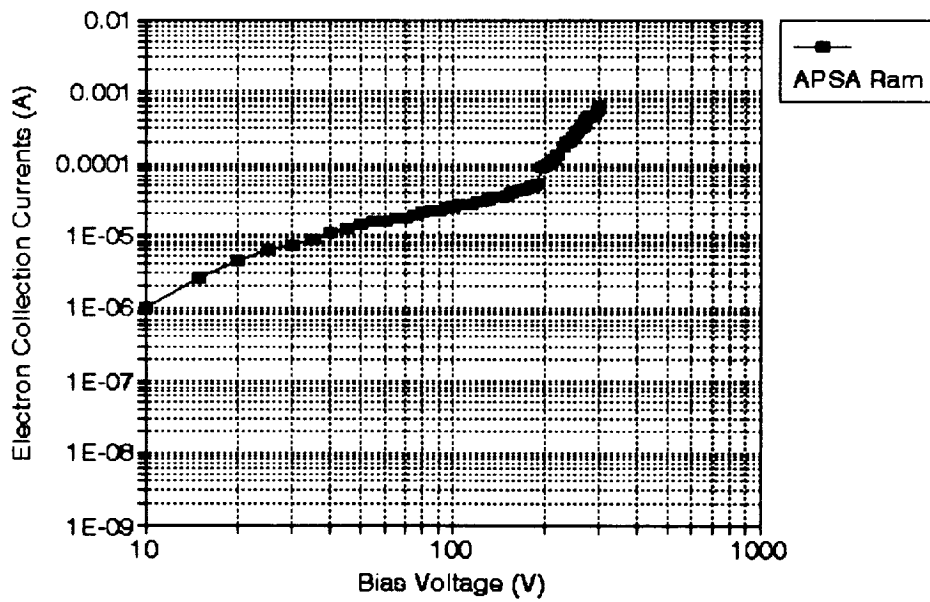


Figure 6. Electron currents collected by the APSA array in the bay-to-ram orientation.



# Space Station Currents, Bay-to-Ram

## Experiment 20

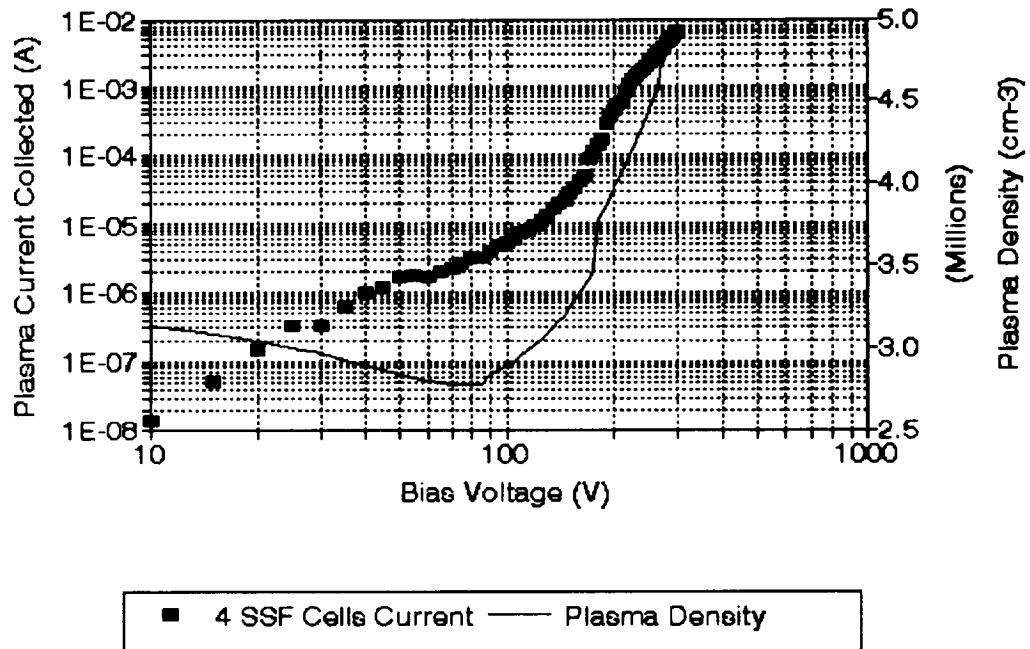
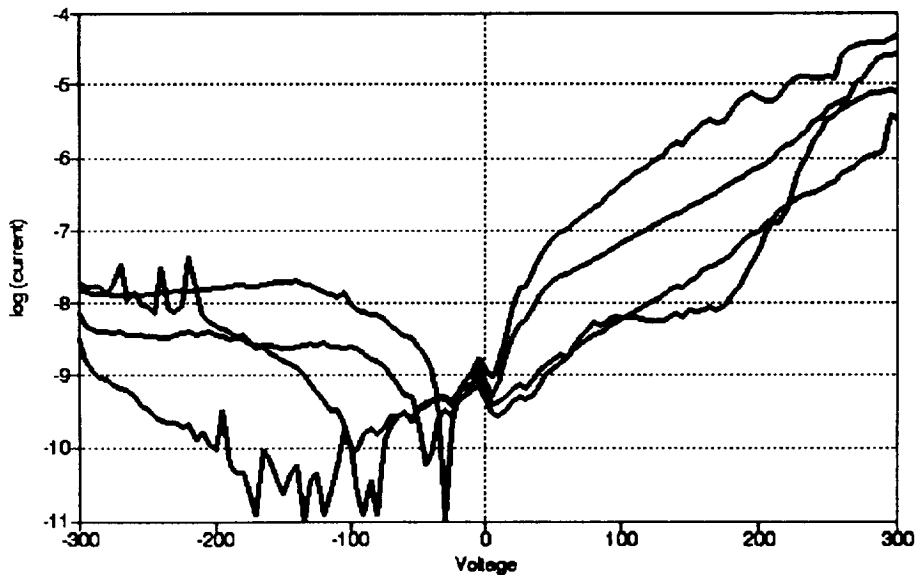


Figure 7. Electron current collection by the Space Station array in the bay-to-ram orientation. Plasma densities are overestimated (see text).

From Exp's 10-13  
Overhang Data



Courtesy of T. Morton

Figure 8. Electron currents collected in the bay-to-ram orientation by Space Station type cells modified to have varying amounts of coverslide overhang.

# SAMPIE DATA - ANODIZED AL

Ram data #2

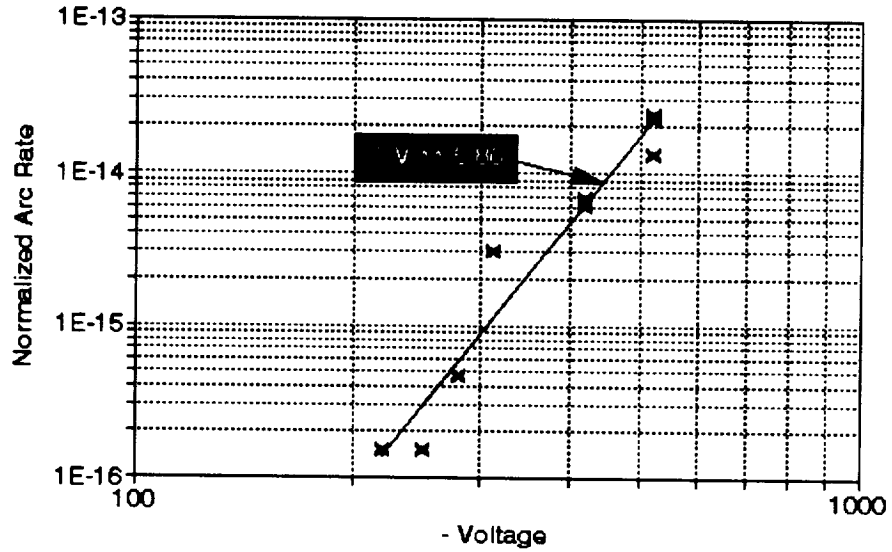


Figure 9. One set of normalized arcing data on the SAMPIE anodized aluminum sample in the bay-to-ram orientation.

# Raw Pressure Data - SAMPIE

MET day 11

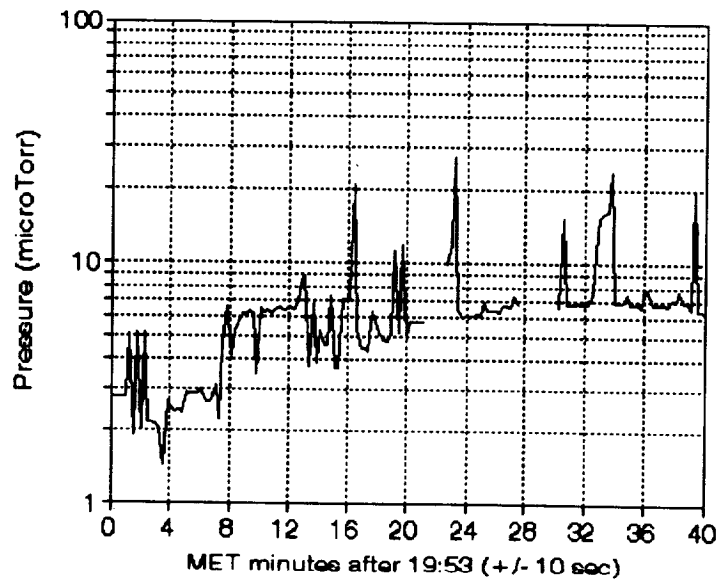


Figure 10. Raw telemetered pressure data taken during EISG experiment operation.