SPACE STATION FREEDOM SOLAR ARRAY PANELS PLASMA INTERACTION TEST FACILITY

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ABSTRACT

The Space Station Freedom and its Polar Orbiting Platform (POP) will operate in Low Earth Orbit (LEO). The electrical environment present at LEO (equatorial) consists of ionized species ranging in density from 10^3 ions/cm^3 to 10^6 ions/cm^3 dependent upon whether the environment is in the sunlight or sunshade period. The electrical environment present at LEO (polar) has a much lower ion density but contains a high energy electron flux which could cause surface charging.

The Space Station Freedom Power System will make extensive use of Photovoltaic (PV) Power Generation. The phase I power system consists of two PV Power Modules each capable of delivering 37.5 KW of conditioned power to the user. Each PV Module consists of two solar arrays. Each solar array is made up of two solar blankets. Each solar blanket contains eighty-two PV Panels. The PV Power Modules provide a 160 V nominal operating voltage. As such, the Space Station Freedom PV Modules will be the highest voltage photovoltaic power system ever used on an American spacecraft.

Previous research has shown that there are electrical interactions between a plasma

environment and a photovoltaic power source. These interactions appear to be related to both the plasma density and the source operating voltage. The interactions take two forms:

1. parasitic current loss - occurs when the current produced by the PV Panel leaves at a high potential point and travels through the plasma to a lower potential point, effectively shorting that portion of the PV Panel.

2. arcing - occurs when the PV Panel electrically discharges into the plasma.

The PV Solar Array Panel Plasma Interaction Test was conceived to evaluate the effects of these interactions on the Space Station Freedom type PV Panels as well as to conduct further research into these interactions.

The test article consists of two active solar array panels in series. Each panel consists of two hundred 8 cm X 8 cm silicon solar cells. The two panels are held together by a hinge pin and are electrically connected in series. The two panels in series provide the aforementioned 160 volts.

The test requirements issued by the Photovoltaic Power Module Division (which is responsible for the design, development and construction of the PV Module) dictated specifications in the following areas:

Plasma Environment/Plasma Sheath
Outgassing
Thermal Requirements
Solar Simulation
Data Collection Requirements

These requirements were incorporated into the design of the PV Plasma Interaction Test Facility. The facility consists of a vacuum tank, cage, solar simulator, cold wall, plasma sources, and a data acquisition/control system.

INTRODUCTION

The Space Station Freedom's nominal operating voltage for photovoltaic power sources has been selected as 160 volts. In order to qualify this operating point, it was necessary to test two full size Space Station Freedom type Photovoltaic Panels (PV Panels) each 420 cm X 40 cm (165" X 15") in a simulated low earth orbit (LEO) environment with respect to pressure, temperature, and plasma. Solar flux was also simulated but at 0.30 solar constant. The primary area of concern was the plasma environment which can cause two undesirable effects:

1.   **PARASITIC CURRENT LOSS**--This results when current from a photovoltaic array leaves the array at a high potential point and travels through the plasma to a low potential point, effectively bypassing the output of the array.

2.   **ARCING**--This results when a array electrically discharges into the plasma.

Both of these phenomena tend to be functions of the array operating voltage and the plasma density of the environment.

The test (which ran from March to October, 1989) was located in the Electric Power Laboratory (EPL--Building 301) at Lewis Research Center (LeRC). Vacuum Tank 5 was used to provide the LEO pressure simulation, a gaseous nitrogen (GN2) cold wall provided the temperature simulation, a light-bank provided the solar flux simulation and various types of plasma sources provided the plasma environment simulation. The data for the test was collected by a PC-based data acquisition system designed specifically for the test. The test is modeled on tests previously performed by the Power Technology Division at LeRC. This test was unique in that it utilized state-of-the-art, large-size solar cells (8 cm X 8 cm) that are planned for use on the Space Station Freedom's photovoltaic arrays. It is critical to ensure this technology can be safely incorporated onto the Space Station Freedom. This report will present detailed descriptions of the major components that constituted the facility for the PV Panel Plasma Interaction Test.

TEST DESCRIPTION

The test assembly was built on a large cage structure (see Fig. 1) which could roll in and out of the vacuum tank to decrease tank "down time." Most electrical connections used quick-disconnect type connectors for the same

reason. The two PV Panels were placed in this cage on a vertical plane along the vacuum tank's centerline. On one side, the PV Panels were illuminated by a solar simulator and on the reverse side they were cooled by a GN2 cold wall. The solar simulator was also cooled on its reverse side by radiation to a GN2 cold wall known as the solar simulator cooler. The PV Panels were electrically loaded using a variable resistance load bank with provisions for short circuit and open circuit conditions. Array temperatures were monitored and recorded by means of thermocouples mounted on the PV Panels positioned to provide optimal statistical data. A bias supply that could be connected to either the positive or negative terminal of the PV Panels, with either positive or negative polarity applied, was provided to drive the PV Panels positive or negative with respect to the voltage potential of the plasma (see Fig. 2). This bias supply was connected in series with the PV Panels. A digital storage oscilloscope was used to capture and record arc waveforms. Electrical parameters were recorded and displayed by a computer controlled data acquisition system. To improve test speed, accuracy, and repeatability, the computer also controlled variation of the test parameters. Automatic calibration features assured data validity.

Essentially, the test involved biasing the PV Panels to positive voltages with respect to plasma voltage potential and measuring/recording the current flow from the bias power supply to the array. This current represents the parasitic plasma current. The PV Panels were then driven negative (while recording plasma currents) until arcing occurred. These tests were done for plasma densities of 10^2 to 10^6 particles/cm^3 (10^3 to 10^7 particles/in^3). Finally, tests were done to investigate and characterize arcing. In order to provide baseline performance data of the PV Panels, they were flash tested at atmospheric pressure at the beginning of the test. This required illuminating the PV Panels with a high intensity (1 solar constant), short duration light source and placing a variable load across the PV Panels' output. This provided a complete current vs. voltage (I-V) curve for the array. The PV Panels were flash tested periodically throughout the test to verify their operational integrity.

CAGE

The photovoltaic test panels and all vacuum exposed support hardware for the PV Plasma Interaction Test were mounted on a self-supported aluminum structure referred to as the "cage" (see Fig. 1). Primarily, the cage was designed to fulfill two functions:

1. To support the vacuum exposed test components as a single transportable package

2. To provide appropriate positioning between the test article and the support hardware

By supporting the vacuum package on one structure which was easily inserted or extracted from the vacuum tank, the facility could accommodate other users by reducing tank "down time." Constructed of ASA 6061-T6 aluminum alloy channel, the cage structure rolled in or out of the tank on removable 304 stainless steel rails. The shape of the cage is approximately an octagonal cylinder and its dimensions are 4.3m H X 3.7m W X 5.2m L (14.0' H X 12.0'W X17.0' L).

To obtain a large volume to accurately simulate the plasma environment of LEO, all test support hardware was required to remain clear of a 168 cm (66") region around the PV Panels called the "plasma sheath." The cage allowed the array to be mounted within the plasma sheath and also provided clearance from the diffusion pump protrusions near the bottom of the vacuum tank.

SOLAR SIMULATOR

The solar simulator (see Fig. 3) was designed to provide a 0.20 solar constant --275 W/m^2 +/- 10% (25 W/ft^2)--within 168cm (66") of the solar array test article while minimizing the amount of heat flux transmitted to the cold wall. The solar simulator was required to evenly illuminate an area of 420 cm X 80 cm (165" X 30") which was the area of the test article.

Two hundred and fifty-two (252) type 'DED' Multi-Mirror Phillips lamps were chosen for use on the solar simulator. These bulbs reject 60% of their infrared (IR) output to the rear. The lamps were chosen for use on the solar simulator based on the following criteria:

1. more optically efficient than line voltage lamp
2. low wattage
3. operation at full voltage possible which would result in good spectral characteristics
4. will not overheat at full voltage
5. ability to be mounted through a solid panel so that no shielding of electrical connections from the plasma environment would be needed.
6. narrow beam approaches a collimated light source.

Sample bulbs were vacuum tested to ensure longevity under test conditions. The bulbs lasted the life of the test.

The solar simulator was controlled by adjusting the output voltage of eight (8) Sorensen DCR 150-70A and two (2) Sorensen DCR 40-250A DC power supplies used to provide power (20 KWe). The supplies were individually monitored and controlled. Bulb burnout was detected by monitoring and comparing the current flow through parallel strings of lamps. It was necessary to calibrate the power supply settings for each operating point. This was done by monitoring the current output of a calibrated solar cell that was swept across the area of the PV Panel at atmospheric conditions and adjusting each supply until the flux met specifications. Power supply settings were then recorded.

After initial operation in vacuum, it was discovered that bulb base temperatures were exceeding manufacturers recommendations. This problem was rectified by adding cooling to the face plate of the solar simulator. This was done by bolting square tubing to the face plate and passing compressed air through it.

COLD WALL

To ensure that the PV Panels maintained an operating range of +20°C to +45°C (+68°F to +113°F), a cold wall (see Figs. 4,5,6) that provided 28 m² (306 ft²) of radiative heat-absorbing surface at -73°C (-100°F) was used to remove heat from the PV Panels. One source of heat was the solar simulator which subjected the PV Panels to a significant heat input (5.0 kWt nominal). In addition to the cold wall, a solar simulator cooler was provided to absorb heat directly from the rear of the solar simulator to reduce the incidence of stray heating.

The cold wall used a regenerative blower to circulate gaseous nitrogen through fin-tube aluminum extrusions to provide the heat-absorbing surface (see Fig. 5). The gas temperature was controlled by injecting liquid nitrogen (LN2) as needed, and by venting GN2 to maintain the 10 PSIG operating pressure. LN2 use was 640 l/hr (170 gal/hr) to maintain operating temperature.

The cold wall system was controlled by means of two independent single-input closed-loop process controllers. They controlled the position of the LN2 inlet valve and GN2 vent valve respectively. The blower output pressure was sensed by means of a high output pressure transducer. The cold wall exit temperature was sensed by means of a type 'T' thermocouple. These two parameters were the control variables. Each of these signals went to a separate Process Controller. The units accepted a variety of inputs and provided an output of 4-20ma based on a PID control algorithm. The current outputs of the

controllers went to Electro - Pneumatic (EP) transducers which converted the electrical signal into a pneumatic pressure of 3-15 psi. The pneumatic signals were used to drive the liquid nitrogen valve and the vent valve. The system was designed for fail-safe operation and included such safety features as:

1. Each valve failed to a safe condition under loss of electrical power or air pressure.

2. Loss of electrical power to gaseous nitrogen blower resulted in system shutdown.

3. A thermocouple was used to detect LN2 accumulating in the cold wall. If detector was tripped, system shutdown resulted.

4. If the above LN2 detector tripped and the LN2 valve failed to close, an alarm sounded and the operator was instructed to manually close the LN2 valve.

5. If the LN2 detector failed to detect liquid nitrogen, there was a second separate detector that activated which instructed the operator to shut the cold wall system down.

6. If the facility lost power, a battery powered alarm notified the operator to close the LN2 valve.

7. If the pressure level of the vacuum tank exceeded a setpoint, the cold wall system shut down.

8. The system was protected by means of electrical relays and burst disks from being started incorrectly or operated in an unsafe manner.

PLASMA SOURCES

The PV Plasma Interaction Test utilized two types of plasma sources to provide the range of densities and types of plasma desired for this test.

CHAMBER DISCHARGE TYPE

Six (6) Pennington-style, hot filament, chamber discharge type plasma sources (see Fig. 7) were used (see Fig. 6) to provide the low density plasma--10^2 to 10^4 particles/cm₃(10^3 to 10^5 particles/in^3). The mechanism of plasma production with this source is as follows. Argon gas is introduced into the discharge chamber at a very low flow rate--10-^{9} standard cm^3/sec(10-^{10}) standard in^3/sec)--and is passed over a hot filament. High energy electrons from the filament strike the argon atoms and remove an electron leaving a positively charged argon ion. A coil around the chamber produces a magnetic field which causes all electrons to travel in a spiral path from the filament to the anode. This longer path length produces a more efficient plasma, as a higher percentage of the atoms are impacted by electrons. Electrons freed from atoms have sufficient energy level to ionize other atoms that they collide with. This cascading effect causes a sharp rise in the anode current as the freed electrons join the electrons from the filament. This rise in anode current (300%+) indicates the production of plasma. There is no accelerating voltage for the plasma. Discharge is accomplished by the higher pressure inside the chamber due to the introduction of the argon. This type of plasma source is controlled by adjusting the DC power supplies that provide electrical power to them. The sources were positioned asymmetrically along the cage.

DIVERGENT FIELD TYPE

A 30 cm diameter J-Series divergent field ion thruster (without the high voltage extraction optics) was utilized for this test to provide the high density plasma--10^5 to 10^6 particles/cm^3(10^6 to 10^7 particles/in^3). This source creates plasma by passing argon down a tube (hollow cathode) and initiating a catalytic reaction to produce plasma (see "Plasma Contactors for Electrodynamic Tether," NASA Tech Memo 88850 for further description). This acts as a keeper or sustainer anode. Gas is then injected around the perimeter of the source which has a positive potential relative to cathode common. This acts as a discharge chamber which provides the high density plasma. The source was placed at one end of the vacuum tank along the centerline of the cage.

DATA ACQUISITION AND INSTRUMENTATION

The PC-based data system--IBM-AT equivalent--(see figs.10,11) used for this test made extensive use of the IEEE-488 General Purpose Interface Bus (GPIB). This enabled instruments of different manufacture to be utilized simultaneously to make a highly specialized test and measurement system with a common interface to a computer. The instruments used for this test and their functions are as follows:

1. KEITHLEY 177 (DIGITAL MULTIMETER)--Array Bias Current measurement

2. KEITHLEY 617 (ELECTROMETER)--Plasma Characterization

3. TEKTRONIX 2430A (DIGITAL STORAGE OSCILLOSCOPE)--Arc Detection and Characterization

4. SORENSEN DAP 488 (DIGITAL TO ANALOG PROGRAMMER)--Bias Power Supply Control

The data system also made use of other computer interfaces. Computer interface cards made by Metrabyte Corporation allowed the computer to read thermocouples and control relays. An Analog-to-Digital (A/D) card was used to read/record such miscellaneous data points as bias voltage, load current, load voltage, electron acceleration voltage, and array end potentials (by reading scaled output of Trek non-contacting voltage probes). All of the data parameters were saved to disk in ASCII format so as to be accessible to such programs as Lotus 1-2-3. In order to characterize the plasma (density, electron temperature,ion temperature, voltage potential), eleven (11) Langmuir probes were used. They were monitored individually using the Keithley 617 mentioned above and a relay card controlled by the computer (see above). The PV Plasma Data System was controlled by software written specifically for this test. This software provided a menu driven program which allowed real time display of performance parameters and other data points as well as provisions for alarm setpoints and graphic displays.
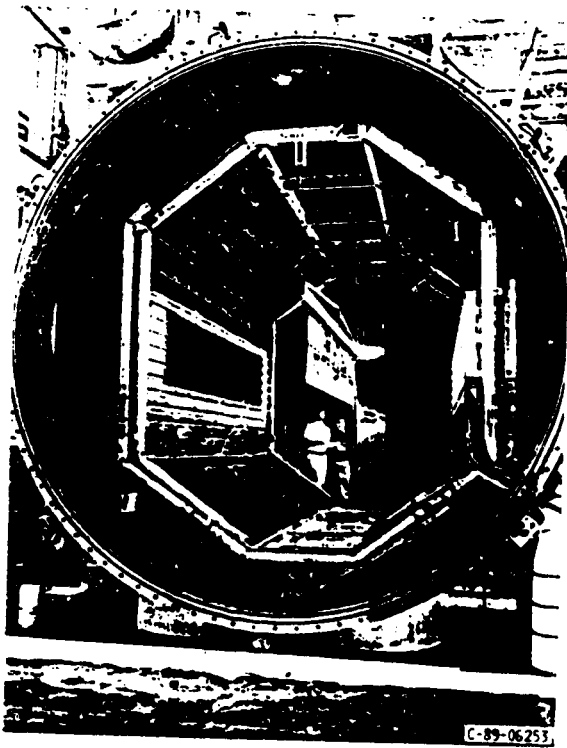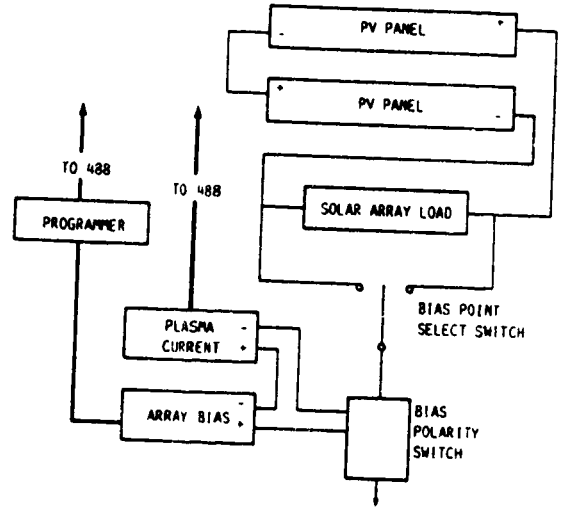
FIGURE 1. - PV PLASMA INTERACTION TEST RIG.
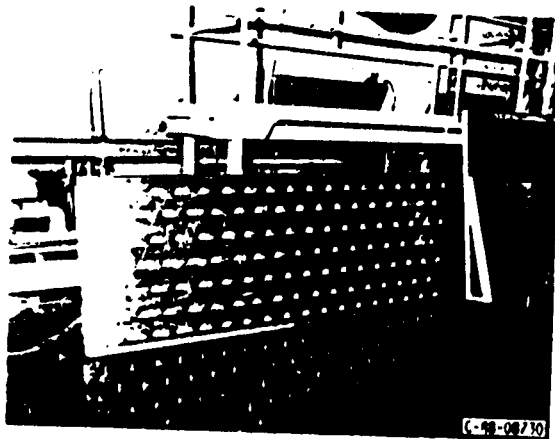

FIGURE 2. - BIAS SUPPLY CONNECTIONS.
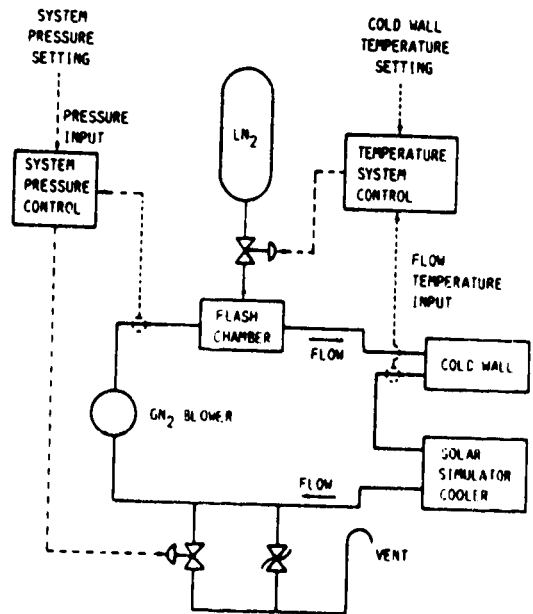

FIGURE 3. - SOLAR SIMULATOR.

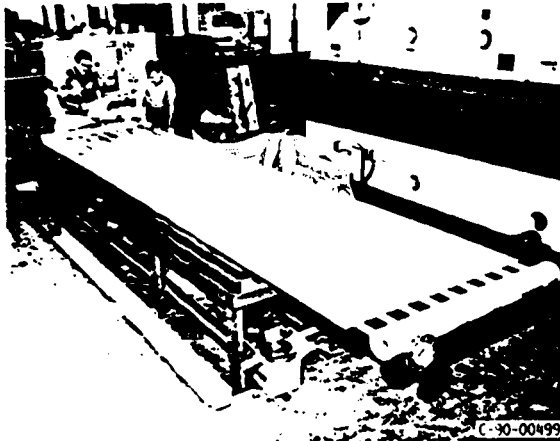FIGURE 4 - COLD WALL SYSTEM SCHEMATIC.

FIGURE 5. - COLD WALL PANEL.
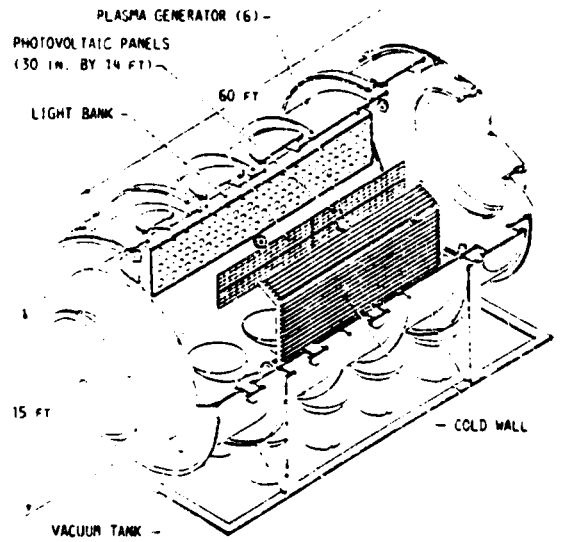

FIGURE 6. - COLD WALL ILLUSTRATION.
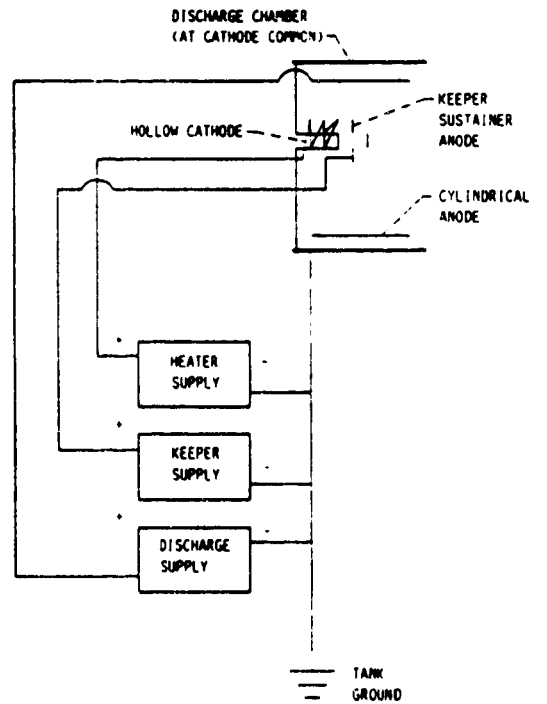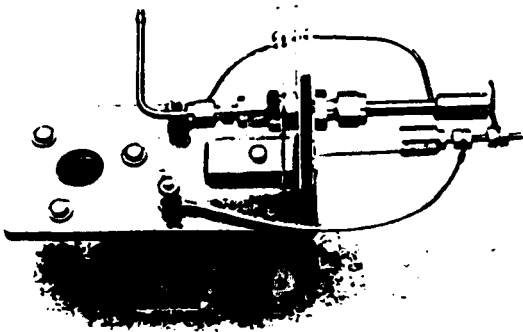

FIGURE 7. - PENNINGTON TYPE PLASMA SOURCE

FIGURE 8. - DIVERGENT FIELD TYPE PLASMA SOURCE SCHEMATIC.
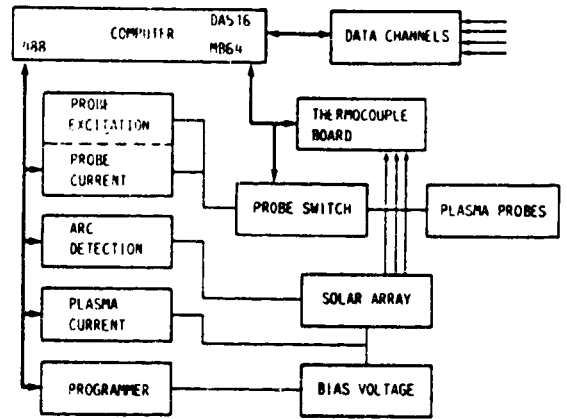
FIGURE 9. - HOLLOW CATHODE PLASMA SOURCE.

FIGURE 10. - DATA SYSTEM DIAGRAM.

FIGURE 11. - DATA SYSTEM

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