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SOLAR ARRAY EXPERIMENTS ON THE SPHINX SATELLITE

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SOLAR ARRAY EXPERIMENTS ON THE SPHINX SATELLITE

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Abstract

The Space Plasma, High Voltage Interaction Experiment (SPHINX) is the name given to an auxiliary payload satellite scheduled to be launched in January 1974. The principal experiments carried on this satellite are specifically designed to obtain the engineering data on the interaction of high voltage systems with the space plasma. The classes of experiments are solar array segments, insulators, insulators with pin holes and conductors. The satellite is also carrying experiments to obtain flight data on three new solar array configurations; the edge illuminated-multijunction cells, the teflon encased cells and the violet cells.

Introduction

Each subsequent generation of satellites tends towards higher power missions. Current electric propulsion missions under study will require solar arrays capable of generating up to 15 kilowatts of power. As the power levels increase, the satellite overall size and weight will also increase. It becomes critical to improve the efficiency of the satellite systems to keep the weight, size and power requirements within practical bounds.

For electrical systems, higher efficiencies are usually associated with higher operating voltages. Studies have been conducted on the high voltage solar array (HVSA) with integral power conditioning that can operate at voltages up to 16 kilovolts.[1-5] These studies conclude that such systems are feasible.

These high voltage arrays, however, will require exposure of high voltage surfaces to the space plasma. Possible interactions between the surfaces and the plasma must be considered in the system design. The interactions that must be evaluated are the current drains between the high voltage system and the plasma, the charge stored on insulator surfaces, and plasma initiated discharges. These interactions must be known as a function of voltage and time in space. Unfortunately, engineering data to design systems that operate over 100 volts in the space environment is not available. As a result of the need for better engineering data, a flight experiment to obtain information on these interactions will be flown. The satellite designed to carry this experimental package has been named SPHINX, an acroynm standing for Space Plasma, High Voltage Interaction Experiment. The experiments will include interaction studies of conductors, insulators, and small solar array segments which can be biased, independently or collectively, in small steps to positive or negative 16 kilovolts. The SPHINX satellite is also carrying experiments to obtain flight data on three new types of solar array configurations; the multijunction, edge illuminated array (MINX), the teflon covered array (FEPSA), and the violet cell array.

Discussion Of The Plasma Interaction

In the standard solar array construction the cover glass does not completely cover the metallic interconnects between cells (see fig. 1). These cell interconnects are at various voltages depending on their location on the array, and when the array is exposed to the space plasma, the interconnects will act as a biased plasma probe attracting or repelling charged particles. At some location on the array the generated voltage will be equal to the space plasma potential (see fig. 2). The cell interconnects that are at voltages above the space potential will attract electrons proportional to the voltage difference. These interconnects that are at voltages below the space plasma potential will repel electrons and attract ions proportional to the voltage difference. This particle flow is a plasma current loop which is in parallel with the electrical load. This current is called the plasma coupling or plasma drain current. Since this coupling current is in parallel with the load current, it will act as a loss, reducing the power available from the array. For solar arrays that generate less than 100 volts, this plasma current is small and the effect can be neglected. As the array voltage is increased, the plasma coupling current represents a progressively larger loss and the effect must be evaluated.

Experimental studies have been conducted in ground facilities to study the interaction of solar array segments biased to high voltages with a plasma environment. A solar array segment of 1058 cm^2 area (476 two cm by two cm cells) was tested in plasma densities of 10^4 to 26 electrons per cubic centimeter.[6] In these tests the segment was not illuminated and the bias voltages were applied from power supplies outside of the vacuum chamber. The results for an array biased to positive voltages are shown in Fig. 3. In general, these results tend to support the prior analytical studies[7,8] that for altitudes approaching synchronous the effect is small. However, these results point out that higher voltage arrays may have to be used only at higher altitudes to avoid serious plasma coupling current losses.

The results for an array biased to negative voltages[6] are shown in Fig. 4. In this case the results are considerably different. The current collection rises rapidly and terminates in an arc which shuts off the laboratory power supplies. The voltage at which the array arced to the plasma is a function of the plasma density and varied from a few hundred volts at a density corresponding to about 15,000 km to several thousand volts at synchronous altitude plasma densities.

A similar study has been conducted at the Lewis Research Center. The array segment was 100 cm^2 area (24 two cm by two cm cells in series) and the bias voltages were provided by an isolated power supply within a fiberglass enclosure mounted inside the vacuum chamber (see fig. 5). The results of this study essentially agree with the results obtained with the larger segment (see fig. 6). The electron currents collected with the segment biased positively increased with voltage for the tests conducted.

The results obtained for negatively biased voltages were the same as those obtained with the larger segment. The array segment arced to the plasma at various voltages depending upon the plasma density. The power supply was designed to shut down, restart and ramp back to the voltage setting when an arc occurred. This arragement allowed observations of several consecutive arcs during a test. These observations of the arcing revealed that glowing spots appeared randomly at the cell interconnects; there was no one specific area that initiated the discharges. This segment was tested

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several times, each test giving the same results. Aside from some discoloration of the metal, there was no apparent damage to the segment (see fig. 7).

This plasma coupling current with the cell interconnects is only one aspect of the high voltage interaction phenomenon. It has been found that insulator imperfections such as small pin holes can result in disproportionally large electron current collection.[6,8,9,10] Furthermore, in the vacuum tank tests, these collected currents have been found to be proportional to the total area of the insulator (see fig. 8). This current collection effect will be evaluated in space by the SPHINX to determine if it must be considered in the design of high voltage systems.

It is recognized that there are serious limitations in the ground test facilities. The uncertain simulation of the plasma environment, the distortion of the electric fields in the plasma by metallic vacuum tank walls, and the high background pressure required to operate the plasma sources probably influence the test results. Hence, it is not possible to state conclusively that the test results obtained to date represent those that will be found in space. A space flight experiment is required to verify the plasma interaction and to obtain the engineering data needed to design high voltage systems for space applications. Such an experiment will be conducted using the SPHINX satellite.

Discussion Of The SPHINX Experiments

SPHINX is a self contained satellite that will be placed into a highly elliptical orbit, 880 km by 34, 300 km, in January 1974. Most of the experiment surface will always face towards the sun. With this orbit the experiments can be conducted in plasma densities that will vary from 1 to 1000 electrons per cubic centimeter over the nominal mission life of one year.

The experimental system on this satellite is designed to study the space plasma interactions over a full range of voltages. Measurements can be made to determine the interaction for voltages up to ±1000 volts. This information can be used in the design of intermediate voltage solar arrays and systems. The satellite experimental system is also capable of biasing the test surface to ±16 kV to obtain the engineering information required to design high voltage systems.

The experimental surfaces of the satellite are shown in Fig. 9. The solar array segment experiments are mounted on tabs at three of the corners of the experiment enclosure. The MINX array is located at the fourth corner. The insulator experiments are located on the experiment enclosure deck, outboard of the solar array segments and on booms. The FEPSA and Violet Cell experiments are mounted adjacent to the main housekeeping solar array on small tabs.

Solar Array Segment Experiments

The solar array segment experiments will be used to obtain engineering data relating to the performance of a high voltage solar array in a space plasma. Each of the 3 segments consists of 24 cells in series. The cells are 10 mil thick, 10 ohm centimeter cells of N-on-P polarity. The covers are 0.012 inch fused silica glass. The nominal output of the array segment is about 1 watt at the expected operating temperature of 65° C.

The potential of two of the segments can be varied over the low and high voltage ranges. The plasma coupling currents will be measured by an electrometer floating in the high voltage circuit. This electrometer is capable of reading currents between 10^{-10} and 10^{-3} amps. An 8 point voltage-current characteristic of the array segment can be measured at any bias voltage.

One of the two array segments has been constructed in the conventional manner with the cell interconnects exposed to allow coupling with the space plasma. This array will be used to determine if the interactions found in the ground facility tests are real or are vacuum facility phenomena. This array will be operated over long periods of time to determine if the plasma interactions change with time.

The second of the array segments that will be biased has the interconnects insulated by a layer of RTV. If the segment performance is similar to that experienced in the ground facility testing (see figs. 3,4, & 6) then the insulation of the interconnects will prevent, or at least reduce, the plasma interactions. The operation of this array over long periods of time in space will tell how well the insulation performs in the space enviroment.

The third segment is identical to the first and will be used as a control surface to separate environmental degradation effects from the high voltage effects.

Insulator Experiments

The insulators being tested are 5 mil polyimide film (kapton) and 5 mil FEP teflon. The bulk resistance of these materials will be determined for both sunlight and shade conditions. Ten experiments are dedicated to the study of the current collection through pin holes in insulators. The insulator experiment construction is shown in Fig. 10. The insulation is about 10 cm in dia and covers the 5 cm dia electrode that is connected to the power supply. The experiment holder is made out of epoxy-fiberglass laminate. The insulation is bonded to both the fiberglass and electrode with a silicone adhesive (Dow Corning A-4000). The pin holes are located in the center of the insulator. The pin hole diameter are 0.041 cm and 0.38 cm. These are the common pin hole diameters for ground test specimens and therefore it will be possible to correlate the data obtained from the SPHINX satellite with existing data.

MINX

The Miniature Interaction Experiment (MINX) is a solar array experiment that uses multi-junction, edge illuminated photovoltaic devices to generate high voltages.[11] In this experimental array, nine segments are used. Shorting switches are used to vary the array output voltages from about 125 to 1125 volts. The overall size of the array is about 280 cm^2. Hence, the experiment will be a small area simulation of a high voltage array. The data obtained from this flight will be used to predict the performance of a full scale high voltage array of this construction.

FEPSA

The purpose of the Lewis Research Center designed FEP teflon encapsulated solar array segment experiment[12, 13] is to verify its performance in a space environment. This type of array which incorporates low cost, light weight construction consists of a laminated package made up of a kapton substrate FEP teflon film solar cell array and an FEP teflon film cover. The package is bonded together in vacuum under heat and pressure to form an encapsulated array.

The flight experiment consists of three FEP covered arrays and one glass covered array as a control. A 16 point voltage current curve will be obtained. This experiment will not be biased to high voltages.

Violet Cell Array

The violet cell array experiment is similar in size to one of the FEPSA experiments. The array utilizes the improved silicon solar cell developed by COMSAT[14] and will determine the effect of the space environment on this type of cell. Glass covers are used. This experiment is not connected to the high voltage circuits.

Concluding Remarks

The NASA is considering a number of missions that will require high power solar arrays. Such missions could achieve significant benefits if the solar array voltages could be increased to 300 volts or higher.

This exposure of a high voltage surface to the space environment can result in an interaction between that surface and the space plasma. These interactions must be taken into consideration in designing a high power space system. Unfortunately, no prior flight engineering data is available on the interactions between insulated surfaces at various potentials and the space plasma. The available experimental data obtained in ground facilities indicates that the interaction can be severe, but it is not certain whether or not these results have been influenced by the facility. A comparison with data obtained in the space environment is required to establish the validity of the ground test data.

A flight experiment will be conducted using surfaces designed to give the engineering data needed. These experiments will be operated in plasma densities that range from 1 to 1000 electrons per cubic centimeter for a period of about 1 year. The interactions studied will be between the plasma and conductors, insulators, insulators with pin holes and solar array segments for a range of bias voltages from 0 to ±16 kV.

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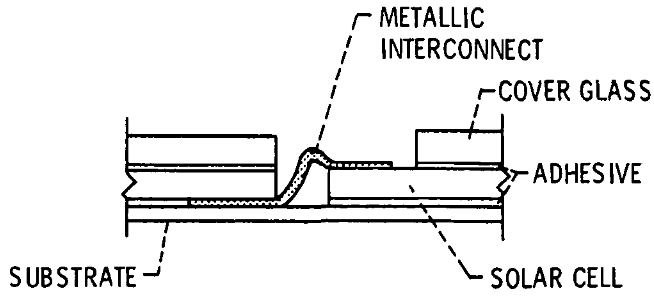
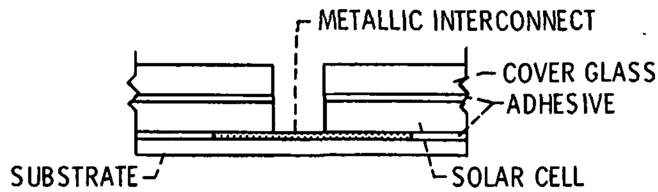


(a) CONVENTIONAL.



(b) WRAP-AROUND.

Figure 1. - Typical solar array construction.

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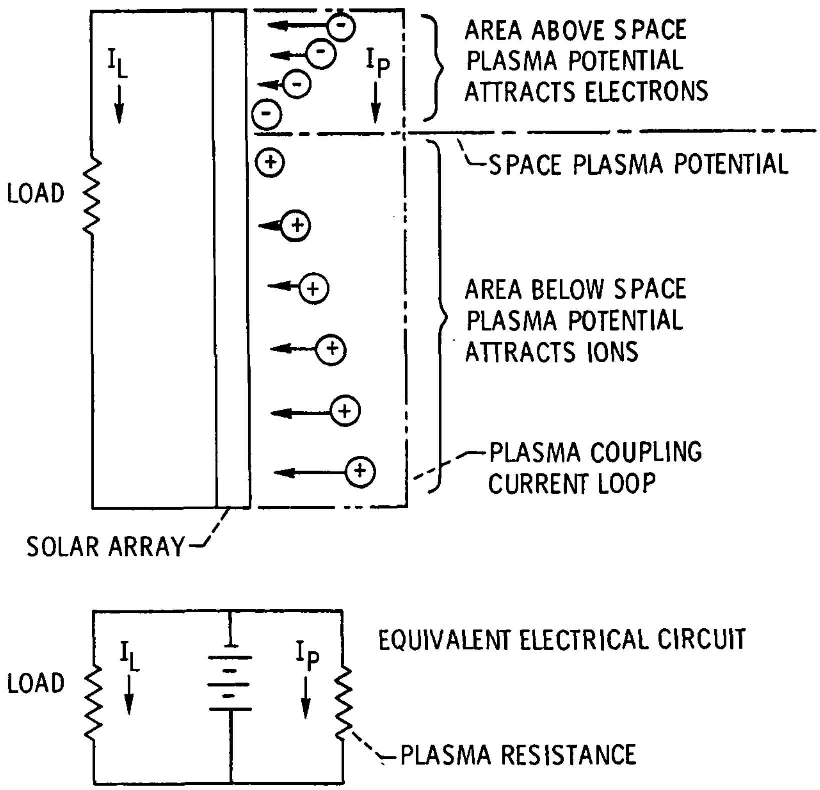

Figure 2. - Solar array-space plasma interaction.

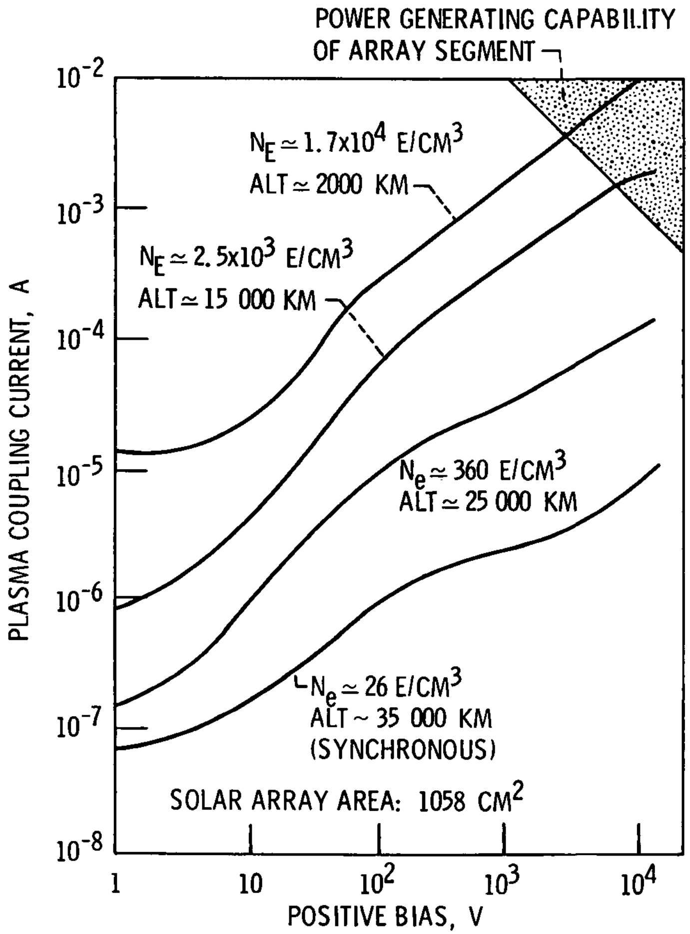

Figure 3. - Array segment plasma coupling current (ref. 6).

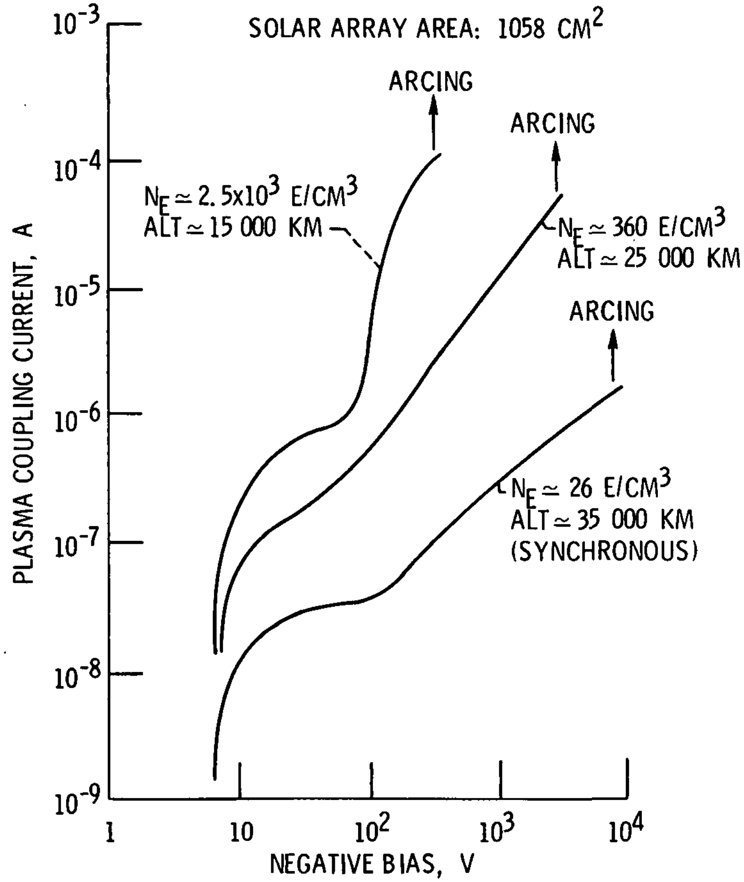

Figure 4. - Array segment plasma coupling current (ref. 6).

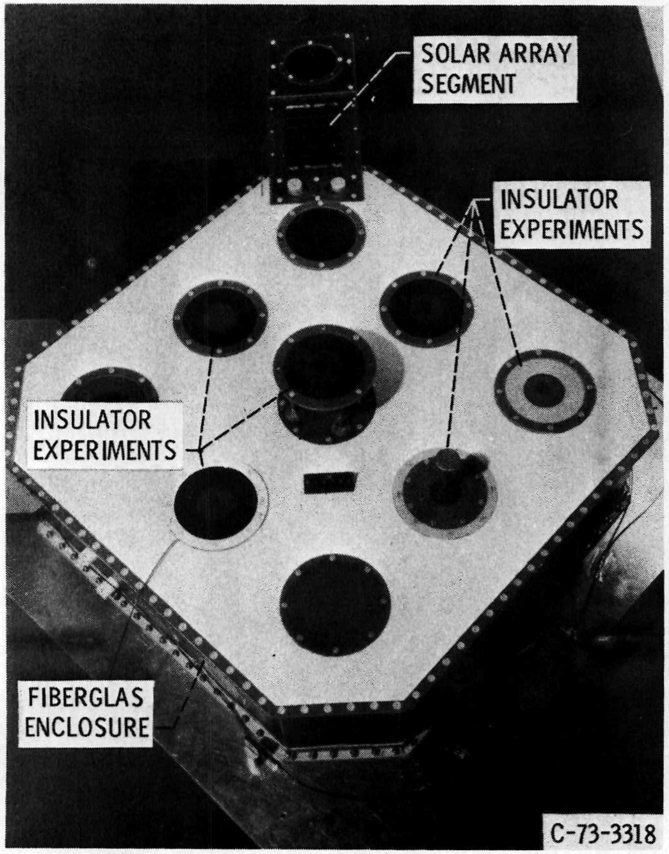

Figure 5(a). - Experimental test apparatus - exterior.

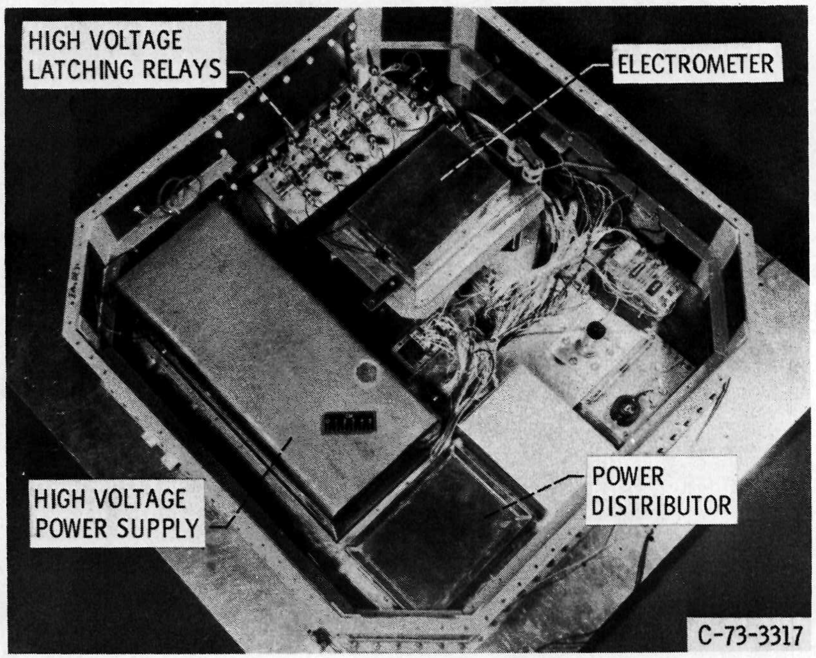

Figure 5(b). - Experimental test apparatus - interior.

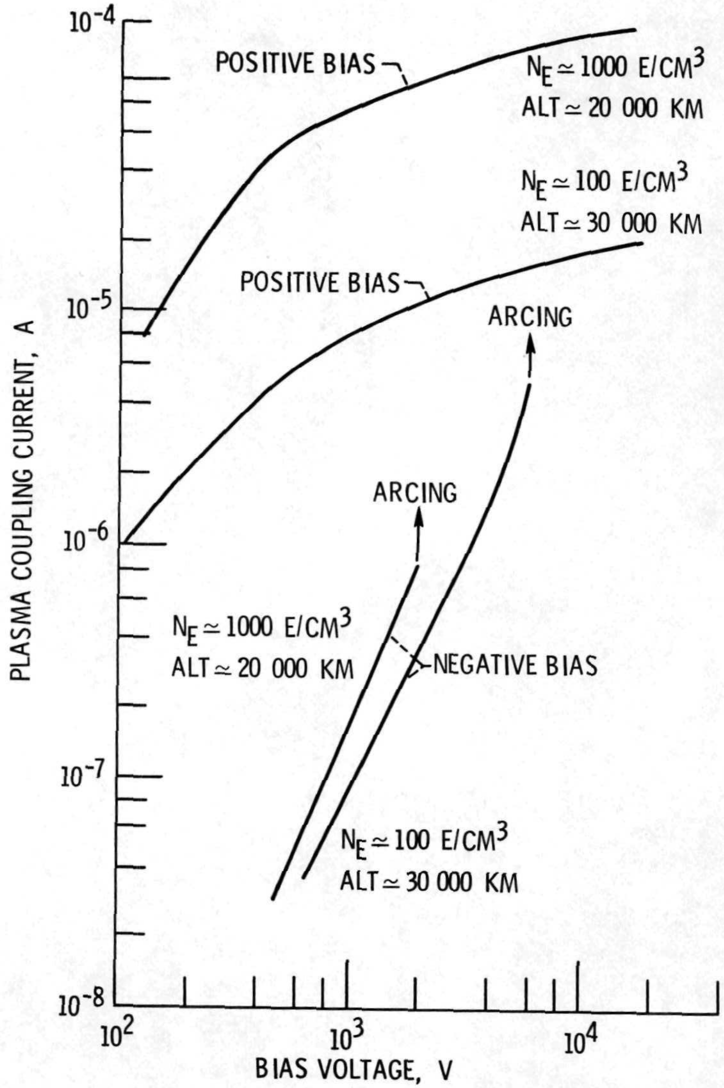

Figure 6. - LeRC array segment plasma coupling current.

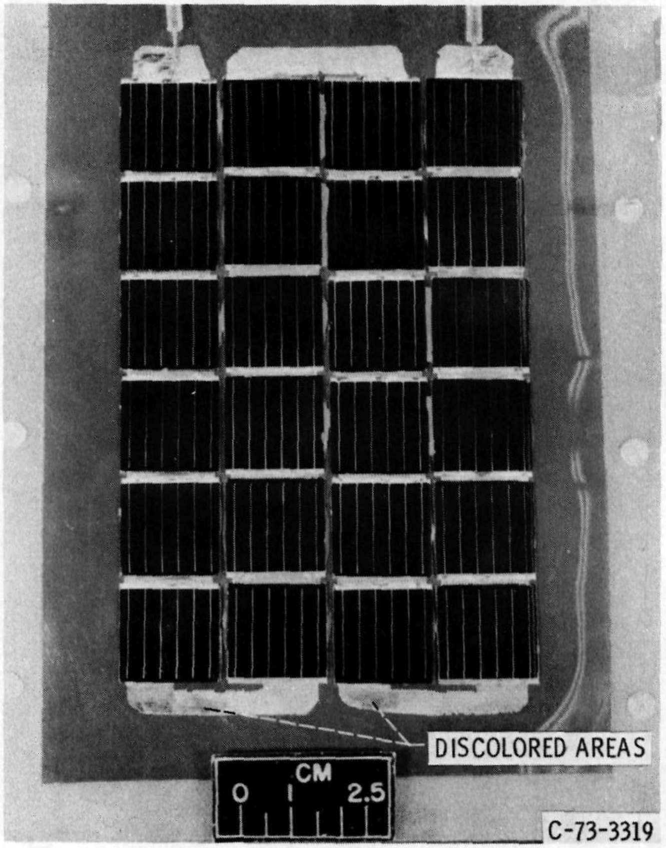

Figure 7. - Solar array test segment.

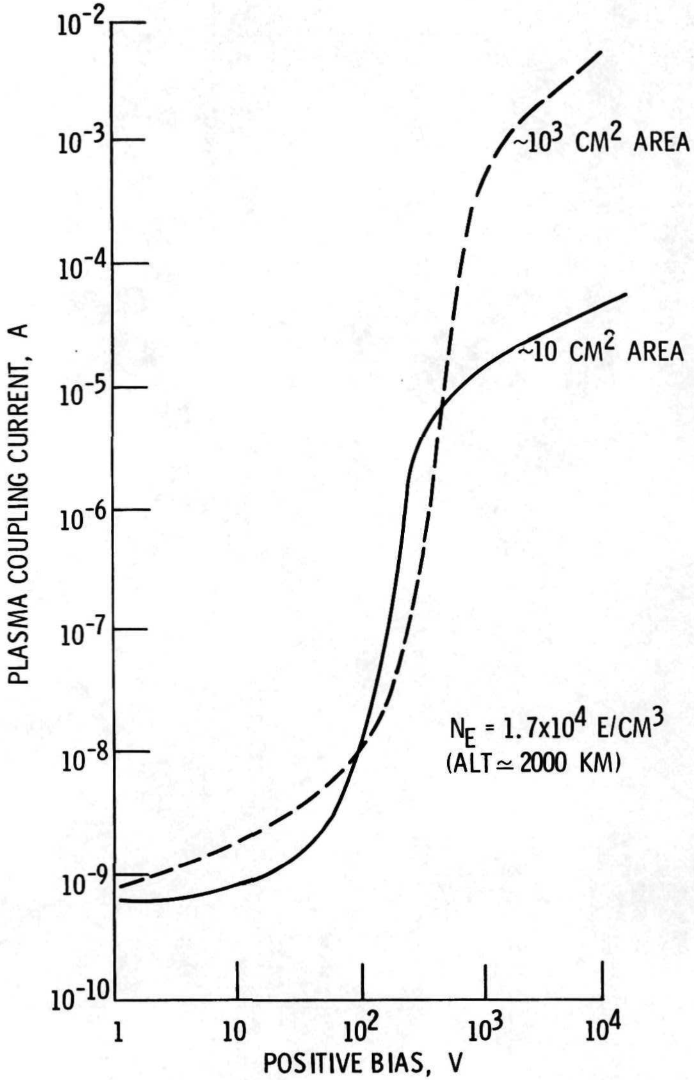

Figure 8. - Effect of insulator area (ref. 6).

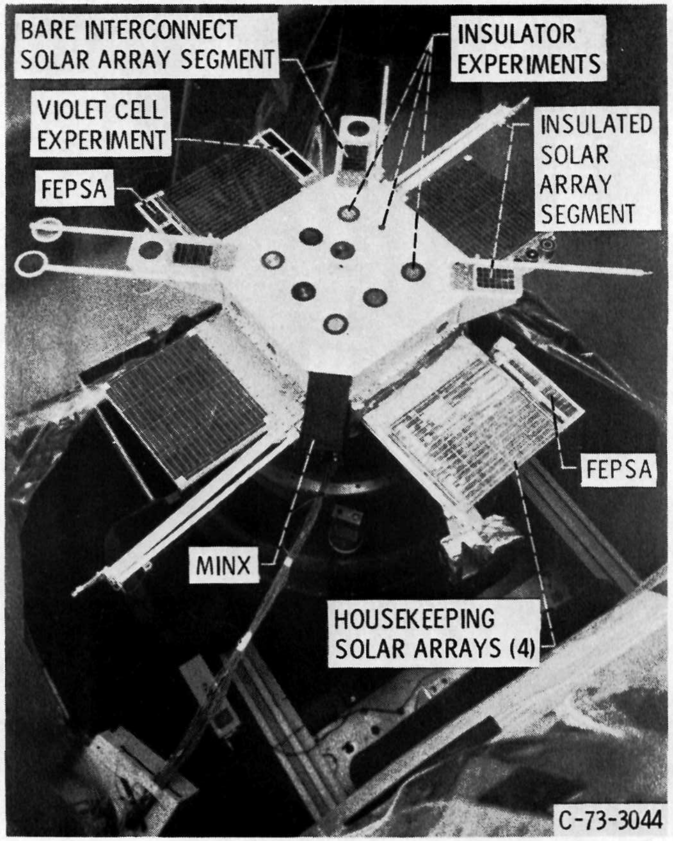

Figure 9. - SPHINX satellite.

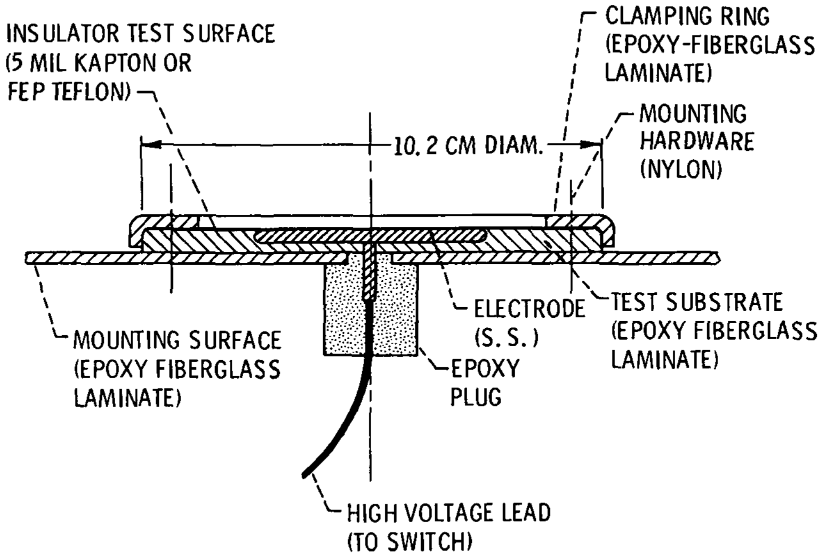

Figure 10. - Insulation test fixture.