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PASP - A HIGH VOLTAGE ARRAY EXPERIMENT

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In the near future, Air Force mission payloads will require significant increases in power. Sophisticated sensing systems such as infrared focal plane detector arrays and radar will be employed by the Air Force to fulfill its strategic objectives. Such payloads will demand that the power subsystem provide up to 50 kW at the end of mission life, more than an order of magnitude greater than is currently required. Some of these payloads must be flown in low-earth (<600 km) polar orbits in order to satisfy mission objectives, thus it is likely that large (500-600 m^2) solar photovoltaic arrays will have to operate in the low-earth polar environment.

The "standard" 28 volt power subsystem is not weight efficient for the array power levels (~50 kW) being considered. Figure 1 illustrates the impact of the solar array operating voltage on the total weight of the array and the subsystem power conditioning and distribution components. Therefore, in the interest of reducing power subsystem weight, higher array operating voltages must be considered. This, however, introduces new problems for the array designer, as will be discussed.

In order to provide a maximum return on the tremendous investment of resources (many hundreds of million dollars) required to develop and place these assets in orbit, they must be designed to operate effectively for extended periods of time (up to 10 years). To achieve this capability, the system must be able to function in the threat-induced and natural space environment.

Traditionally, the major natural threat to Air Force assets has been the relatively high energy (>100 keV) portion of the space radiation environment. A tremendous accumulation of flight data plus characterization of the radiation environment has allowed ground test methods to be developed that adequately simulate the effect of this environment on the performance of solar arrays.

However, within less than a decade, a large body of evidence has been accumulated that powerfully argues that the low-energy space plasma (<100 keV) environment will be the major natural threat to the next generation of Air Force systems, regardless of orbit. The SCATHA and PIX-1 flight experiments (Ref. 1, 2) have clearly indicated that plasma-induced events are capable of producing catastrophic effects on the spacecraft's operational capabilities, including failure of the spacecraft.

Although the space plasma environment has been fairly well characterized, it can easily be perturbed by natural changes in the earth's magnetosphere or the presence of a relatively large (>100 m^2) spacecraft subsystem or payload such as a solar array or radar. The interaction of the perturbed plasma with such a body can lead to conditions that produce high voltage discharges, current leakage to the plasma, and electromagnetic interference. Plasma-induced arcing can lead to sudden significant losses in array power or in the worst case, total loss of power. Electromagnetic interference can compromise the operations of other subsystems or the payload in a completely random fashion. Array current drain to the plasma is a situation that may prove to be a threat to the performance of the solar array.

The PIX-1 experiment verified laboratory experiments conducted on small (~100 cm^2) array samples. Also, the PIX data confirmed the observation that for positive bias voltage, the plasma coupling current changes from being proportional to the amount of exposed array interconnect area at below 100 volts to being proportional to the total array area at above 250 volts. The magnitude of the post transition (>250 volts) plasma coupling current was also shown to be related to the space plasma density. Of even greater significance, array discharge (arcing) was produced at negative voltage levels which agreed with ground-based experiments.

The present view, based on the PIX results plus NASCAP computer modeling studies, is that the effect of high positive array bias voltage is of minor concern compared to the effect of high negative voltage which is more likely to be predominant over most of the area of large solar arrays operating in the space plasma environment. However, it should be pointed out that PIX-1 only confirmed the results obtained in laboratory tests of small array samples. PIX-1 did not use an array test sample that was operating in sunlight, nor was data obtained on photoelectrically-generated plasma interactions that may occur when the array enters sunlight from occultation. Finally, PIX-1 did not experience the effects of an auroral substorm-induced plasma environment. The proposed Photovoltaic Array Space Power (PASP) experiment is aimed at providing this kind of data as well as acting as a check on the PIX data.

The PASP experiment, which is being sponsored by the Air Force Wright Aeronautical Laboratories, Aero Propulsion Lab, (AFWAL/APL) has been designated to be one of the elements comprising the Interaction Measurement Payload for Shuttle (IMPS) multiprobe experiment package scheduled to be flown in late calendar year 87 or early 88. IMPS will be a free-flier experiment, released from a Vandenburg launched Shuttle and planned to function in a noon/midnight, low-earth polar orbit, for up to eight days. The carrier for the IMPS package is to be the Shuttle Pallet Satellite (SPAS), which was built by MBB and has flown from previous NASA shuttle missions.

The IMPS multi-probe will consist of a complex environmental measurements experiment being developed by the Air Force Geophysics Laboratory (AFGL), the PASP experiment, and at least two other instrument packages designed to assess the influence of the low-earth polar space environment on materials and components essential for the success of future Air Force missions. Due to the limitations associated with the amount of attitude control gas carried by the SPAS, the critical portions of the PASP experiment are being sequenced to obtain the essential data during four consecutive orbits. Since the PASP requirements have to be coordinated with those of other IMPS experiments, it is not yet possible to accurately describe the PASP experiment sequence.

PASP OBJECTIVES

The objective of the PASP experiment is to develop an instrument package that, operating in conjunction with a number of conventional and potentially survivable Air Force array designs, will provide engineering and scientific information concerning the influence of the low-earth polar orbit plasma environment on solar array performance.

There are six main data objectives for the PASP experiment. The first, and most important from an engineering sense, is to determine how much the array samples discharge or arc as a function of negative bias voltage, space plasma density, and plasma temperature, since these measurements will be made in both polar regions and the equatorial (higher plasma density) portion of the orbit. The second objective is to measure electromagnetic interference (amplitude, rise-time, polarity, etc.) generated by the array samples when they arc. This will hopefully be done for both hard-wire and radiated components.

The third objective is to measure the array samples' current leakage to the space plasma, a potential power loss factor, as a function of positive bias voltage and plasma environment. The fourth objective is to measure the plasma density and temperature in the vicinity (<50 cm) of the test arrays. The fifth objective is to measure the power output and temperature of each array under actual (illuminated) operating conditions. This measurement is very important since it will likely be the first time that certain array designs (concentrator) are flown in space. The final objective is to verify or modify more cost-effective ground simulation techniques, including computer modeling and plasma-chamber testing, particularly for the as yet untested concentrator designs.

PASP INSTRUMENT DESCRIPTION

The experiment is planned on the assumption that the PASP instrument package will contain: (1) a Langmuir probe to measure the plasma environment in the very near (<50 cm) vicinity of the test array modules, (2) an I-V curve tracer to measure the power output of each test array, (3) a sun sensor to assure proper array test conditions, (4) a high voltage power supply to negatively and positively bias the test arrays to a maximum of 500 V in controlled steps, (5) a wide dynamic range electrometer to measure coupling currents over the range of 1×10^{-6} to 1 A, and (6) temperature sensors (thermistors) on each array module. Electromagnetic interference will be measured by a transient pulse monitor included in the IMPS environmental measurements experiment.

There will be five different types of solar array modules tested. Each module will be mounted as an electrically isolated entity from spacecraft common. There will basically be three types of measurements performed on each module: (1) current-voltage (I-V) characteristic curves, (2) DC plasma coupling current as a function of positive and negative bias voltage with the module in an open-circuit voltage mode, and (3) AC "noise" as a function of positive and negative voltage in the open-circuit mode. In this open-circuit mode, the modules will actually be loaded with a very high impedence, allowing a minute current flow, thus insuring proper voltage gradients across the modules. Any "noise" generated by the arrays due to interactions with the space plasma will be measured and recorded by a companion experiment also on the SPAS. A sixth advanced technology cell design module may also be included for I-V curve testing, depending on availability in time for the flight. A complete description of the proposed test modules will be provided in a subsequent section of this paper.

Both of the above-described measurements will be performed when the modules are oriented normal to the sun within plus or minus one and one-half degrees. Sun orientation will be performed by gas thrusters on the SPAS controlled by commands from the Shuttle, based on signals received from the sun sensor mounted on the PASP panel.

This tight sun pointing requirement is necessary to obtain accurate I-V data on the power output of the concentrator test modules. Slight deviations in the acquisition of the sun by the concentrator optics will cause the amount of energy focused on the solar cells to be substantially reduced. For example, the mini-Cassegrainian module will lose almost seven percent of the incoming solar energy if the misalignment to true sun normal is only about two degrees (Ref. 3). The sun angle tolerance for the Survivable Low Aperature Trough System (SLATS) concentrator design is equally stringent (Ref. 4), thus requiring the plus or minus one and one-half degrees sun pointing. The data acquisition described above is planned to be performed during four successive Earth orbits after the SPAS has been released from the shuttle bay and placed in a free flier mode.

During any orbits in excess of the four in which attitude control is available, the PASP will be put into a drift mode. In this mode, the silicon array module will be biased by a "constant" voltage (probably about -300 V) and the leakage currents, arc discharges and sun incidence angle will be monitored regularly; about every second for the plasma interaction events and every five to ten minutes for the sun angle. Also during this time, the Langmuir probe will be acquiring information about the plasma environment around the test module. The information obtained during this drift mode will provide a sort of "map" of the entire low-earth polar orbit and how the array module interacts with it while at a high negative voltage.

Figure 2 shows a block diagram of the proposed PASP instrument. It is assumed that the SPAS vehicle will provide the battery power and data recording capability to support the PASP instrument during the free-flight portion of the IMPS mission.

PASP TEST MODULES

Five solar array modules will be tested as part of the PASP measurements package. Module 1 will consist of 100 series-connected silicon solar cell assemblies (covered solar cells) mounted on an insulated aluminum honeycomb substrate. The cells will be nominal 2 cm x 4 cm in size and are representative of the type now used for Air Force missions. Module 2 will consist of 100 series-connected by two parallel-connected gallium arsenide (GaAs) solar cell assemblies, 2 cm x 2 cm in size, mounted on the same type of substrate as the silicon array module. The cover glass and adhesive will be the same as that used for the silicon module.

Modules 1 and 2 are representative of the standard configuration now used for arrays and will act as benchmarks for the other three test modules and as a basis of comparison to previous flight data from the PIX-1 experiment. Modules 3, 4 and 5 represent advanced Air Force array designs that show high potential for survivability. Their unique configurations also make them well suited to significantly expand the existing scientific data base on the subject of plasma interactions.

Module 3 will be composed of an eight element concentrator using GaAs solar cells. This design, known as the mini-Cassegrainian concentrator (Ref. 3), is capable of providing an effective solar concentration of approximately 80 times normal.

Module 4 is another concentrator configuration, SLATS (Ref. 4). The baseline design consists of a semi-parabolic primary reflector which also serves as a thermal radiator; compound elliptical second-stage optics for gathering off-axis rays, and in-line GaAs solar cell assemblies mounted at the exit aperture of the second stage optics. The module will be approximately three times the size of the mini-Cassegrainian, or about 0.75 ft^2.

Module 5, designated Integral Cover Array (ICA), is a conventional silicon solar cell module, except that it will be totally encapsulated using a deposited dielectric coating composed of silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). The thickness of the deposited layer will be between 3 and 5 mils since it is required to offer adequate protection to the solar cell from the low energy proton environment of space. The module will be approximately the same size as the mini-Cassegrainian.

A sixth module may be included for the purpose of measuring its I-V characteristics. This module will consist of 10 to 25 AlGaAs/GaAs stacked multi-bandgap solar cells. Inclusion of this module, however, depends on the availability of MBG cells. At the present time, the prospects for including this sixth module in the PASP package look rather dim.

GROUND TESTS AND MODELING

As previously mentioned, an important part of the PASP objective is to verify existing ground test techniques for solar array performance in the low-earth polar environment. This verification is particularly important for the advanced design modules which have not yet been flown in space. To achieve this goal, the PASP experiment will be "simulated" in two ways; computer modeling and plasma-chamber exposure. The flight-data will be compared to the ground tests which can then be verified for accuracy or modified using the flight-data as a basis.

Preliminary computer modeling of PASP has been performed at NASA-LeRC by an Air Force Institute of Technology (AFIT) student, Capt. Karl Reichle, for AFWAL/APL using the NASCAP/LEO code. The objective of this preliminary modeling was to define the plasma environment around the SPAS vehicle during execution of the PASP experiment sequence and to establish what effects PASP-induced potentials have on the remainder of the SPAS. Initial results indicate that biasing the largest PASP array modules (Si or GaAs) to high voltages drives the SPAS ground potential much less than expected. A complete report on this modeling is expected in June 1985, at which time more concise quantitative information will be available.

Future modeling using the NASCAP/LEO code will incorporate more accurate information on other experiments aboard the SPAS vehicle (as it becomes available) and will involve investigating widely varying array potentials, plasma environments, and resulting plasma-coupling interactions. Similar computer modeling will be performed using the POLAR code at AFGL, which is designed specifically for analyzing the polar orbit environment, as opposed to LEO, which is designed for general low-earth orbits.

Plasma-chamber simulations will be performed by NASA-LeRC on sample modules representative of the actual PASP flight array modules. These simulations will be composed of exposing the array samples to different plasma environments under different bias voltages and monitoring any interactions. It should be interesting to see how the flight data compares with these results, particularly for the concentrator designs with their inherently large exposed metal surfaces and the ICA module which has very little exposed conductor area due to the interconnects being covered.

CONCLUSIONS

The PASP experiment has the potential of providing a great deal of significant information on both the low-earth polar plasma environment and its influence on the performance of advanced survivable arrays that will be necessary to support future Air Force missions operating in this challenging environment. It is also likely that the initial flight will generate new questions that may require additional flight experiments. Anticipating this, the PASP experiment is being designed to be easily modified and reflown.

It is worth observing that the current status of our understanding and appreciation of the major impact that the plasma environment can have on photovoltaic power systems is akin to the situation faced by array designers in the early 1960s when it became obvious that the natural high-energy space radiation environment had been badly underestimated. The PASP and the NASA-Lewis VOLT (voltage-operating-limit-test) experiments are examples of the growing appreciation that DOD and NASA are now attaching to understanding the space plasma environment.

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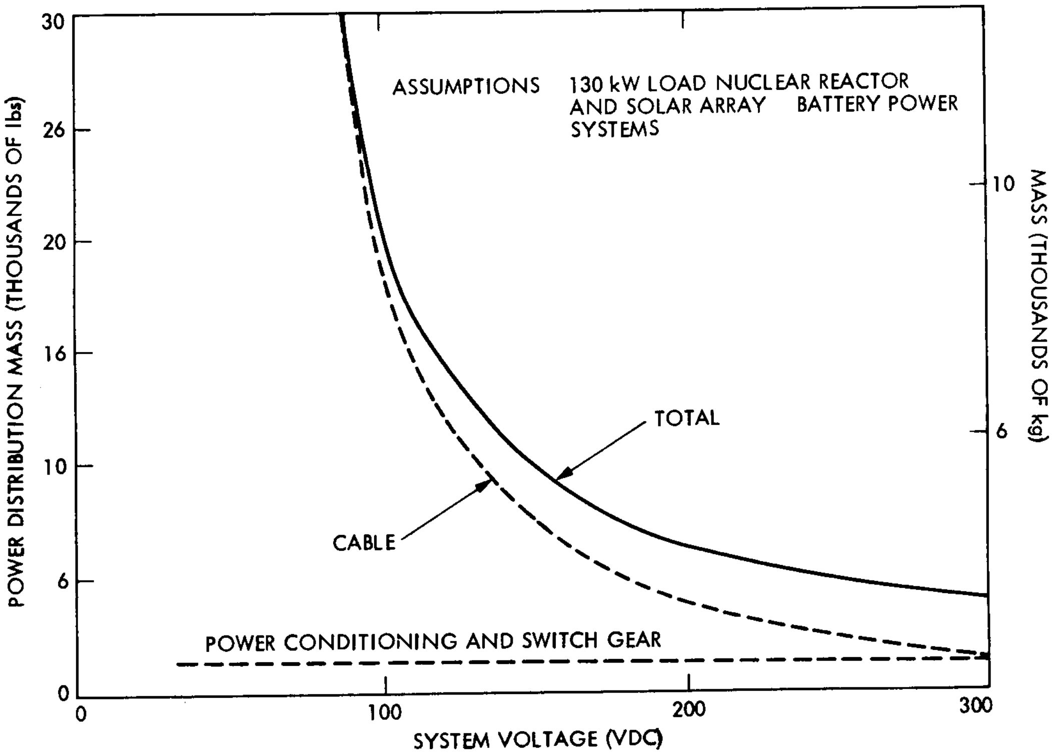

Figure 1. Effect of Array Operating-Voltage on Power System Weight

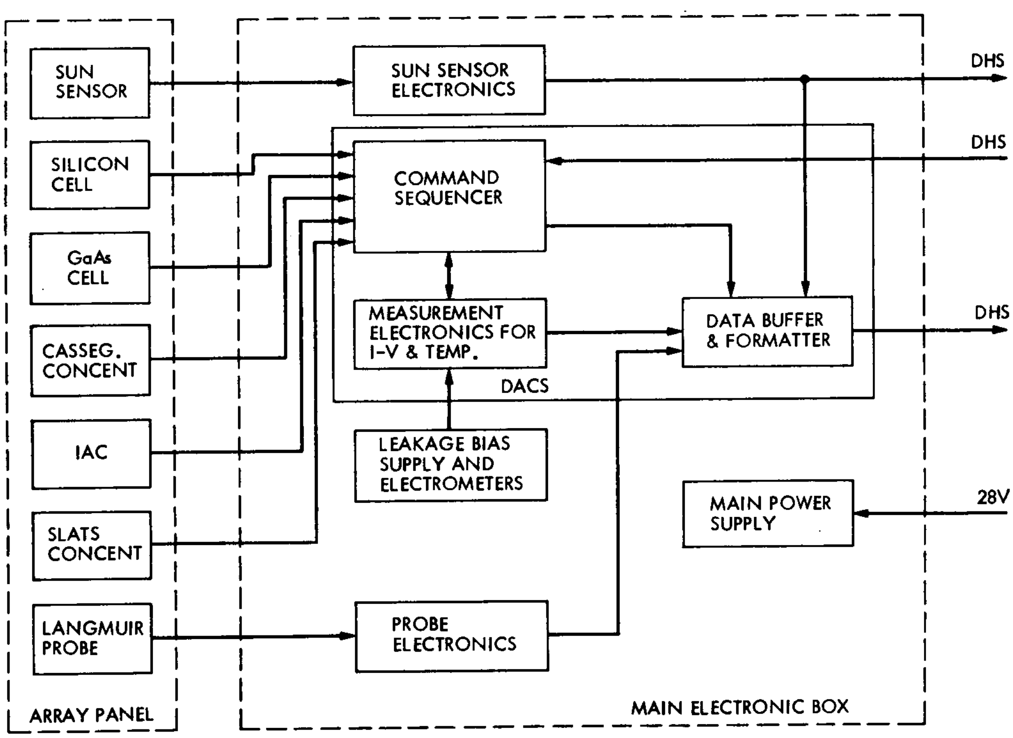

Figure 2. PASP Instrument Block Diagram