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Pico Satellite Solar Cell Testbed (PSSC Testbed) Design

30 September 2007

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The PSSC Testbed flight experiment is designed to obtain accelerated space environment degradation data for advanced solar cells. The acceleration factor, with respect to total dose radiation for operational missions, will be obtained by flying the PSSC Testbed in a Geosynchronous Transfer Orbit (GTO). The resulting data will provide DOD and commercial users of advanced solar cells insight into the actual performance of these solar cells before they are flown as the power supply of a multimillion dollar satellite.

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1. Introduction

The PSSC Testbed flight experiment is designed to obtain accelerated space environment degradation data for advanced solar cells. The acceleration factor with respect to total dose radiation for operational missions will be obtained by flying the PSSC Testbed in a Geosynchronous Transfer Orbit (GTO). The resulting data will provide DOD and commercial users of advanced solar cells insight into the actual performance of these solar cells before they are flown as the power supply of a multimillion dollar satellite.

The two U.S. solar cell manufacturers, Spectrolab and Emcore, are starting production of a new generation of high-efficiency solar cells on a two- to three-year cycle. These new cells are committed to fly on major DOD or commercial space assets as soon as they are placed in production. Presently, with the accelerated introduction of new solar cell technology into the production, the first time that these new-technology solar cells actually are flown will be on a major satellite program. This has, in the past, resulted in unexpected interactions with the space environment, which caused either failure of the solar arrays or significant degradation of performance, limiting the ultimate useful life on orbit. Ground testing of new solar cell technology consists of sequential exposure of different solar cells of the same design to the various elements of the space environment. These elements include radiation (electrons, protons, gamma rays), thermal cycling, atomic oxygen (LEO orbits only), ultraviolet light and visible light illumination, and micrometeoroids. Thus, the combined (synergistic) effects of these individual components of the space environment are not tested for and determined prior to flight on a major DOD or commercial spacecraft.

To address this problem, there is a need for responsive space flight capability to test new solar cell technology within the time cycle for introduction of the new technology and before the launch of new satellites with the new solar cell technology. The Aerospace Corporation has developed a pico satellite spacecraft bus, which includes a solar power system with the capability to characterize new solar cells. This picosat could be the starting point for the development of a responsive space vehicle that would provide the capability of obtaining actual space environment exposure of new solar cell technology in a time frame that is in sync with the new generation solar cell's introduction cycle. Once this vehicle is flown successfully and demonstrates its capability, the spacecraft bus can be used as a standard testbed for any type of future solar cells with minimum modification.

2. PSSC Testbed Description

The PSSC Testbed flight experiment is designed to provide the United States Air Force with space flight data that will be used to validate performance models for new multijunction solar cells. The total size of the PSSC Testbed is 5 in. by 5 in. by 10 in. The satellite will have four Emcore Very High Efficiency solar cells mounted on each of two sides and four Spectrolab XTJ solar cells mounted on each of two sides, which have dimensions of 5 in. by 10 in. Figure 1 shows the engineering development unit of the PSSC Testbed body with the Emcore Solar Cells mounted on it.

The pathfinder mission for the PSSC Testbed will fly in a Low Earth Orbit (LEO), and has been manifested on the STS 126 mission scheduled to launch in September 2008. This mission will allow verification of the PSSC Testbed spacecraft systems and operational concepts.

Operational PSSC Testbed missions will fly in a Geosynchronous Transfer Orbit (GTO). This orbit will provide accelerated radiation exposure, as shown in Figure 2. Missions in a GTO would allow the acumination of several years of equivalent radiation exposure as compared to a Geosynchronous Earth Orbit (GEO) in a very short period of time. The electronics consist of a stack of circuit boards, each with their own function that are shock and thermal isolation mounted in the interior of the satellite body (Figure 1). Also, there are sensor daughter boards mounted to the exterior of the satellite for various sensing functions, which feed back information to the aforementioned electronics stack. The function and quantity of circuit boards that control the satellite operations and draw power from the bus are: (1) Flight Computer; (1) radio; (2) battery voltage upconverter and battery charger boards; (1) solar voltage upconverter board with peak-power tracking circuit; (1) Inertial Measurement Unit (IMU); (1) Attitude Control Board (ACB); and (1) Camera Board with VGA cameras (optional). The sensor daughter boards mounted on the interior wall of the satellite include (4) sun sensor daughter boards and (4) Earth sensor daughter boards. Torque coils, in three orthogonal planes, are used to control the satellite attitude. In addition, there are two reaction wheels, which are aligned along the long axis of the spacecraft. One reaction wheel will be spun up using power from the launch vehicle before ejection from the Picosatellite launcher. After ejection from the Picosatellite launcher, the reaction wheel will spin down and impart a spin rate of 2 RPS to the PSSC Testbed. The second

Figure 1. Photograph of the PSSC engineering development spacecraft body.

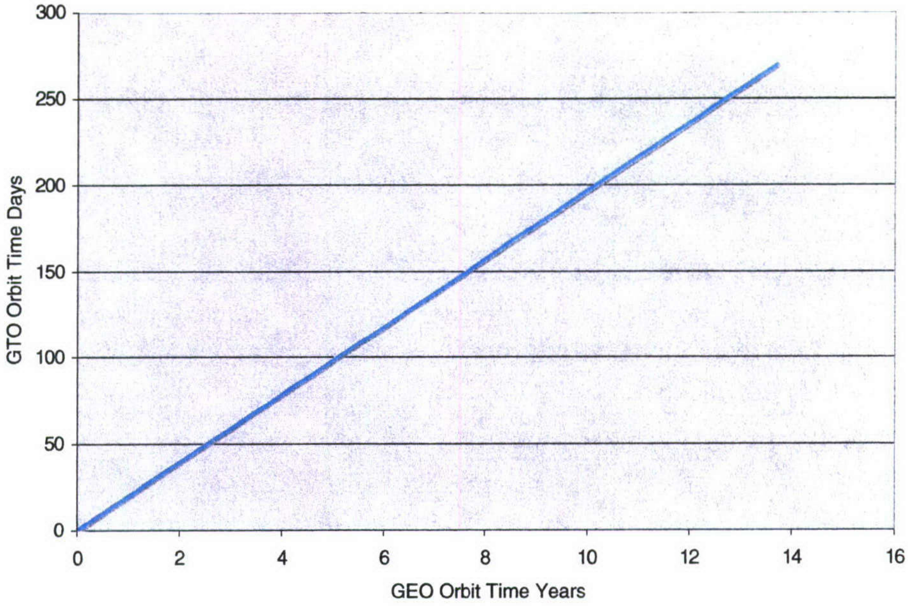

Figure 2. Radiation exposure acceleration between GTO and GEO orbits.

reaction wheel will be spun up to reduce the spin rate of the PSSC Testbed to 2 RPM to make measurements of the solar cell current-voltage characteristic. It is planned to include a radiation sensor and GPS receiver in the PSSC Testbed for operational missions, which will fly in the GTO orbit.

There are three electronics bays available in the 5 in. by 5 in. by 10 in. Picosatellite. The payload electronics package described above **will not** use all three of the available bays in the Picosatellite. Thus, the PSSC Testbed could become a standard Picosatellite bus for a wide variety of space flight experiments with a minimal cost, including space components other than solar cells. Figure 3 provides a photograph of a typical Picosatellite Electronics Module, which would occupy one of the three bays available in the PSSC class of picosatellite. The Reaction wheels will occupy a portion of the remaining two bays. The space not occupied by the reaction wheels is available for a secondary payload.

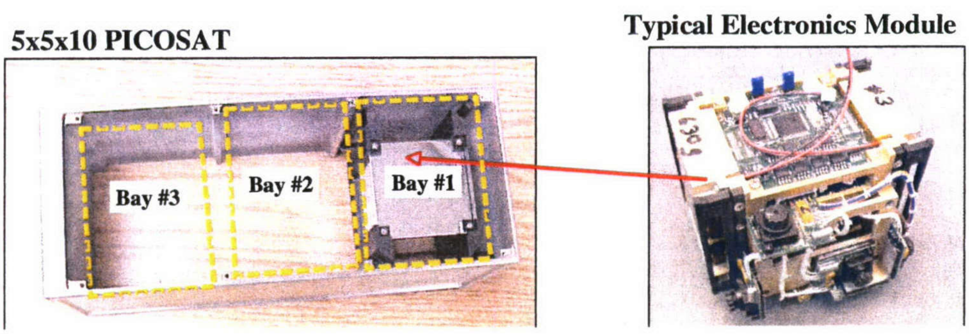

Figure 3 Picosatellite Configuration

3. Description of Operation of PMAD

The PSSC Testbed Power Management and Distribution (PMAD) systems utilize the "Ring Bus" power system architecture. This architecture was originally developed for the PowerSphere.[1-3] The configuration of the major elements of the PMAD for the Ring Bus is shown in Figure 4. In this configuration, each of the individual power modules sense the voltage on the "Ring Bus," which is set nominally at 10 VDC.

The Solar array regulators, shown in Figure 5, have a microprocessor and a DC-DC converter in each. The solar array on each face of the PSSC Testbed has the four solar cells connected two in series with the two series strings connected in parallel. Two of these arrays on opposing faces of the PSSC Testbed spacecraft are connected to a single solar array regulation unit through blocking diodes. For operation in the sunlight portion of the orbit, the first level of the control loop is the Pulse Width Modulated (PWM) DC-DC boost converter, which provides a regulated bus with voltages between 9.5 and 10.5 V. If left alone, this PWM DC-DC converter would increase the current demand on the controlled solar array beyond the peak power point. If this happens, the power output of the converter would collapse to zero. To prevent this from happening, a microprocessor monitors the bus voltage and output current and implements a peak power-tracking algorithm. Thus, if an increase in current demand from the PWM DC-DC converter results in a decrease in power output, then the microprocessor commands a lower current demand by the PWM DC-DC converter. The microprocessor also monitors the solar array voltage and turns the PWM DC-DC converter off if the solar array voltage drops below 3.0 V and turns it back on when the voltage exceeds 3.2 V. The battery subsystems provide power to the "Ring Bus" when the bus voltage drops below 10.0 V. When the bus is supported by the batteries, the battery microprocessors turn off all of the battery chargers, and goes to a low-power sleep state. The basic building block for the battery subsystem is a battery control element that

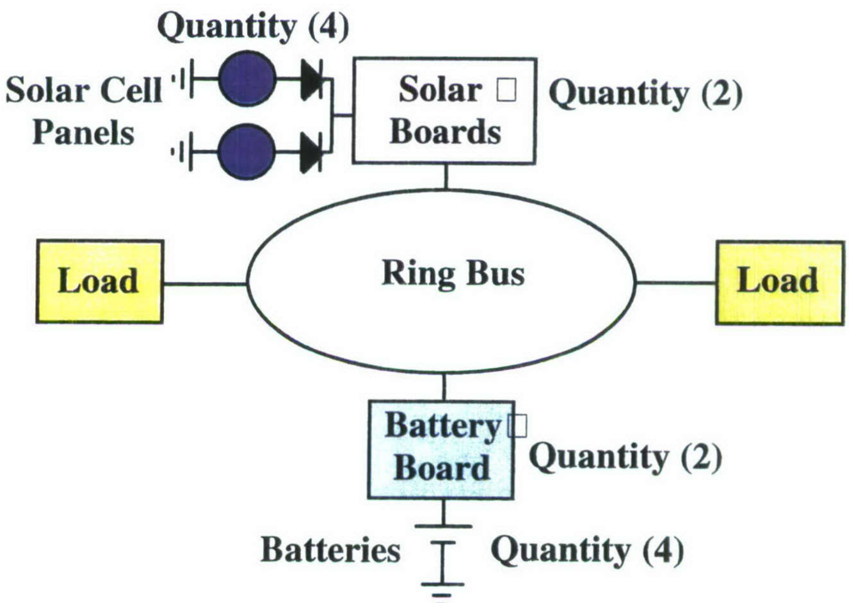

Figure 4. Schematic diagram of ring bus architecture.

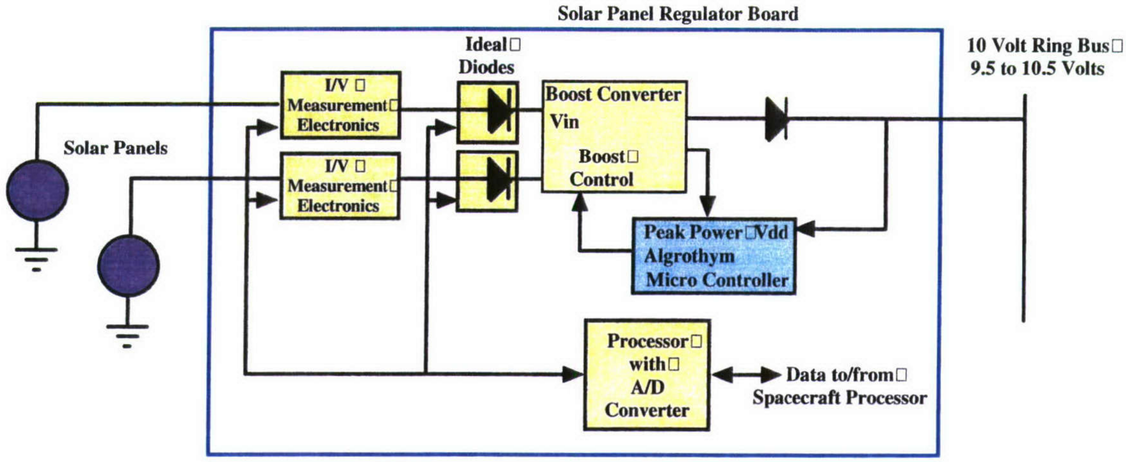

Figure 5. Schematic of PSSC testbed solar array regulator board.

controls the operation of two individual battery cells and their associated chargers and boost regulators. During the sunlight portions of the orbit, the battery building block microprocessor turns off one of the battery boost regulators and turns on the associated battery charger. As the bus voltage increases above 10.1 V, the microprocessor allows the battery to charge with a switch-mode battery charger for Li-ion cell. If the bus voltage decreases due to an increase in load or decrease in solar illumination, the battery charger immediately decreases the charge current. If the bus voltage drops below 10.1 V, the charger turns off, and the boost regulator turns back on.

The Li-ion battery charging algorithm is preprogrammed in the battery charger microprocessor and battery control board. Above 3 V, the cell is charged at a maximum current (constant current mode) of 0.75 A until the cell reaches 4.2 V. At 4.2 V, the charger enters the full top-off mode, which charges the cell at the constant voltage. In constant voltage mode, the charger regulates the maximum cell voltage to 4.2 V. If, for any reason, the cell voltage exceeds 4.35 V, the charger goes into fault mode, and power to the charger is turned off to protect the cell. The cell is deemed fully charged when the cell remains at the constant voltage charging at a preset time. The cell with the lowest voltage is charged preferentially to maintain charge balance between cells, unless the cell voltage falls below 3.0 V, which indicates cell failure.

4. PSSC Testbed Description of Current/ Voltage Measuring Circuit

The PSSC Testbed is able to measure the Current/Voltage Characteristic of the solar cells that are used to provide electric power for the satellite due to the unique ring bus architecture used for the power system. The solar cells on each face of the spacecraft can be disconnected from the individual boost converter for that solar array panel by turning off the Ideal Diode used as a blocking diode for each array.

As shown in Figure 6, the current from each solar array is passed through a 0.1-ohm shunt resistor. The voltage drop across this resistor is amplified by an operational amplifier to increase the level, which represents the solar array's current by 2 V/A. This signal is used in the I/V controller as a feedback for the current control circuit, and is routed to the A/D converter for I/V data. The voltage on the bus is measured concurrently with the current measurements for each current step. The I/V controller drives the base of transistor Q1 to deliver specific current steps from open-circuit to short-circuit conditions to the 0.2-ohm load resistor. The result of this process is the measurement of a high-fidelity I/V curve for the PSSC Testbed solar arrays. Figure 7 is a sample I/V curve for one of the four PSSC Testbed solar Arrays.

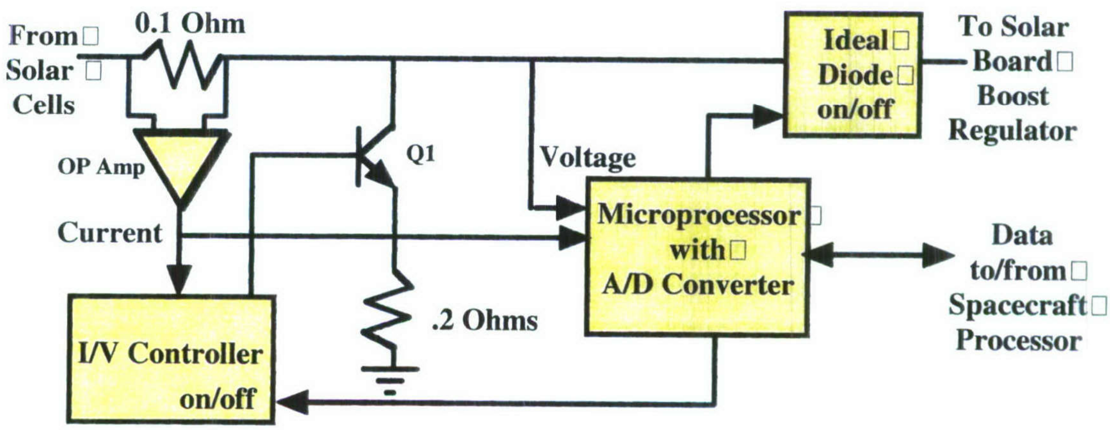

Figure 6. Schematic of the current/voltage characteristic measuring circuit.

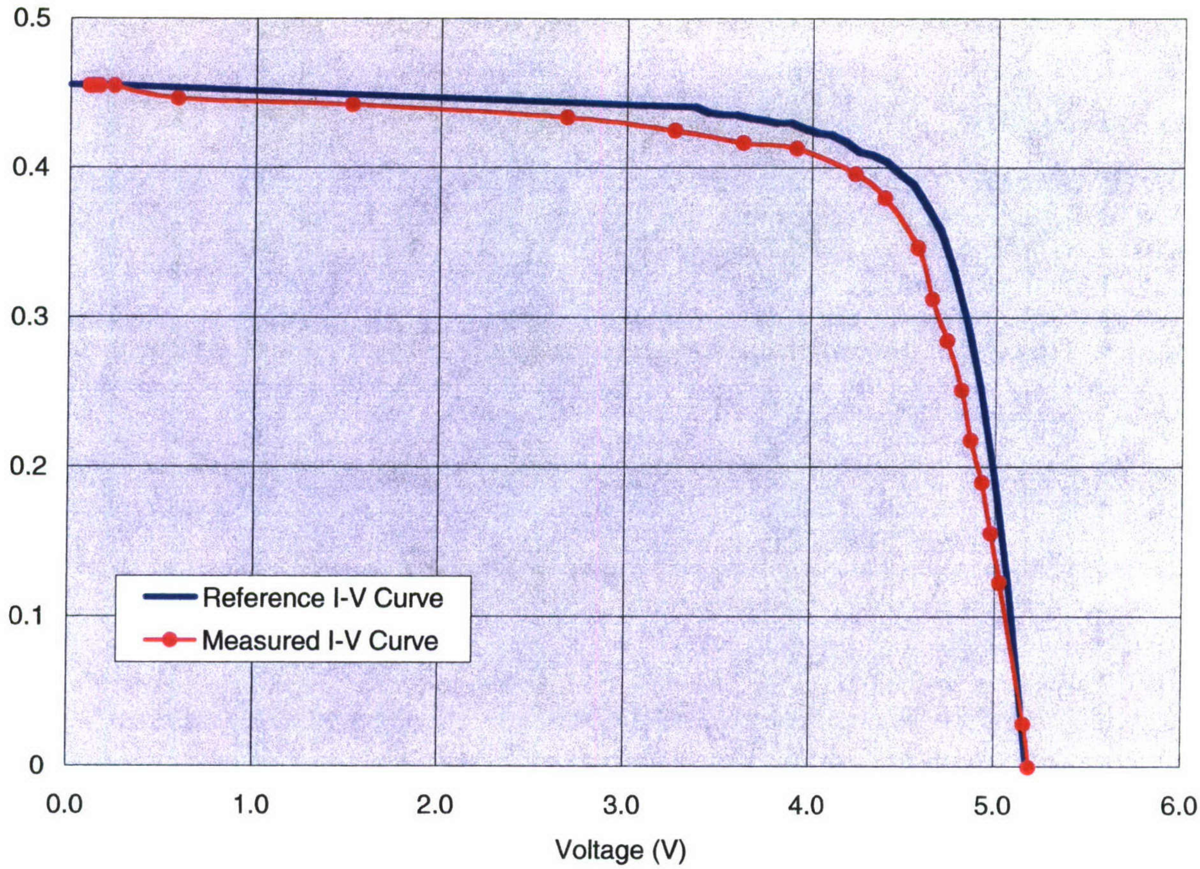

Figure 7. Current/voltage (I/V) measurements of PSSC testbed solar array compared to ground reference measurements.

5. Relevance of the PSSC Testbed

The Solar cell manufacturing industry has a long history of performing ground-based qualification tests on solar cell technology. Presently, there is an effort underway to produce a solar cell qualification standard, which is being spearheaded by The Aerospace Corporation and the Air Force SMC. One of the items identified by this effort is the need for early flight of new-technology solar cells before they are flown on a major DoD or NRO space asset. There have been several commercial and military spacecraft that have failed or had the useful life of the spacecraft reduced due to unforeseen interactions between the space environment and the solar arrays.

Prior attempts to obtain space environment exposure data have failed due to the schedule delays in integration and launch process of the host spacecraft. By the time the flight experiment was finally launched, the solar cell technology being tested already had several years of use on orbit, and the technology was no longer in production. To resolve this problem, the Pico Satellite Solar Cell Testbed is designed as a special-purpose Pico Satellite whose mission is to obtain solar cell performance data on orbit. As a Pico Satellite there are multiple missions on which it may fly. Ultimately, with a Pico Satellite launch capability on multiple EELV missions, a PSSC Testbed could be manifested and launched on demand, thus further reducing the time between initial production of new solar cell technology and the receipt of orbital performance data.

6. Conclusions

With the successful completion of this new technology demonstration, the Air Force and industry can consider the inclusion of requirements for actual space flight data as a requirement for space qualification of new-technology solar cells. This requirement would significantly reduce the risk of unpleasant surprises for major programs due to a lack of knowledge regarding actual space flight performance of new-technology solar cells. Ultimately, the Air Force could sponsor the fabrication and acceptance testing of several PSSC Testbeds that could be pressed into service as soon as a solar cell manufacturer has a new generation of advanced solar cells in the space flight qualification process.

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