TACSAT-4 SOLAR CELL EXPERIMENT: ADVANCED SOLAR CELL TECHNOLOGIES IN A HIGH RADIATION ENVIRONMENT

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ABSTRACT

The TACSAT-4 Solar Cell Experiment will measure the current and voltage characteristics of advanced EMCORE BTJM solar cells thinned to 100 microns and ATJM cells under an 8.5X ENTECH Stretched Lens. TACSAT-4 will fly in a highly elliptical orbit, passing through the electron and proton belts every six hours. This orbit is expected to induce a 25% power reduction in one year due to radiation damage. In addition to demonstrating these new technologies, TACSAT-4 will also demonstrate a radiation hard solar cell measurement circuit designed to a simple interface capable of meeting the standard requirement for future solar arrays built to the *AIAA S-122-2007, "Electrical Power Systems for Unmanned Spacecraft."* TACSAT-4 will launch in September of 2009.

THE TACSAT-4 SPACECRAFT

The TACSAT-4 spacecraft designed and built by the Naval Research Laboratory and the Applied Physics Laboratory, is part of the Operationally Responsive Space (ORS) program designed to demonstrate a standard bus architecture and a communications payload. [i] TACSAT-4 is powered by a 1kW ATK solar array populated with EMCORE ATJ cells. The mission calls for a highly elliptical orbit (HEO) with an apogee of ~12000 km and a perigee of 700 km. This orbit passes through both the proton and electron belts as illustrated in Figure 1. The TACSAT-4 radiation environment is

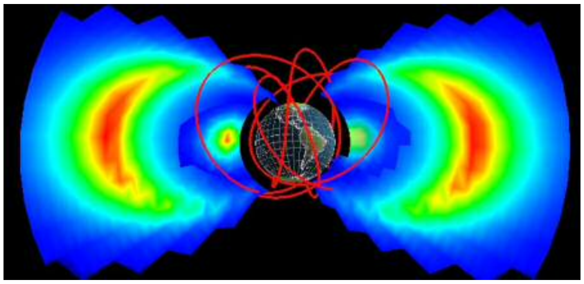

Figure 1) TACSAT-4 Orbit shown in relation to the Radiation Belts.

severe. Using the AP-8 and AE-8 proton and electron environment models along with the NRL displacement damage dose model,
the projected solar array power loss could be as high as 25% in one year. Figure 2 shows the radiation environment is dominated by trapped protons. This is an excellent environment to conduct radiation tests of solar cells as well as verify the prediction methodology for power loss.

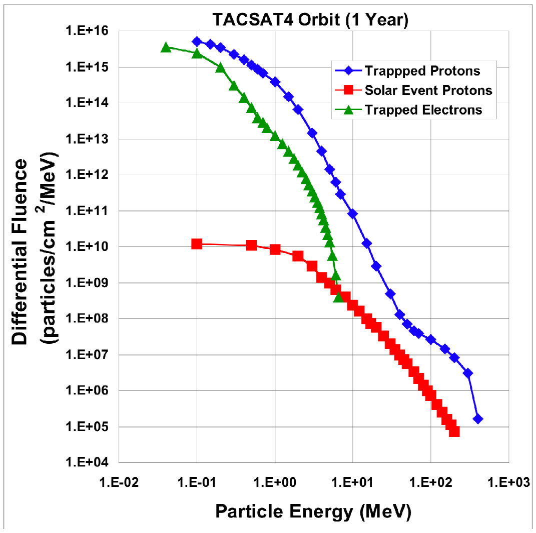

Figure 2) Particle fluence for one year in orbit.

THE TACSAT SOLAR CELL EXPERIMENT

The TACSAT Solar Cell Experiment will measure four solar cell samples. The solar cell technologies being measured are:

1) One 3-cell string of EMCORE BTJM cells thinned to (100) microns.
2) One 3-cell string of EMCORE ATJM concentrator cells under an ENTECH Stretched Lens supported by ATK structure and tensioning mechanisms (SLA). [ii]
3) One thinned (100 micron) EMCORE BTJM cell with POSS filled DC 93-500 silicone serving as a cover glass, mounted on ATK's UltraFlex® gore material.
4) One thinned (100 micron) EMCORE BTJM cell with a 150 micron thick CMG, AR coated coverglass bonded with DC 93-500 silicone and mounted on ATK's UltraFlex® gore material.

Figure 3 shows photographs of the test objects and Figure 4 shows their orientation on the spacecraft. The Stretched Lens sample is on a fixed-frame, fully deployed. The test samples are located on the outside

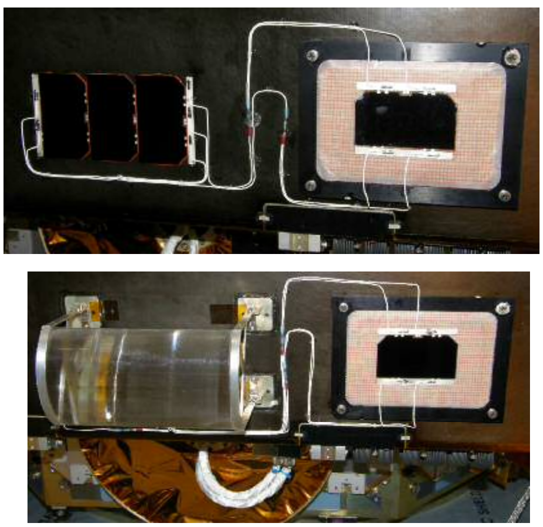

Figure 3) Photographs of the test objects (2) and (4) lower picture, and test objects (1) and (3) upper.

solar panel in the stowed configuration and thus the Stretched Lens can be deployed prior to launch without interfering with the solar array storage. This is somewhat different than the SLA concept that uses a deployable lens mechanism to minimize array storage volume.

The strings will have I-V curve characterization while the single cell experiments are short circuit current measurements. The single cells will compare the efficacy of a POSS® filled DC 93-500 coating compared to CMG cover glass. POSS® is a potential replacement coverglass material suitable for rigid and flexible solar cells. [iii] The POSS® is being supplied by Hybrid Plastics. EMCORE applied the POSS® coating to the solar cell using their integrated CIC line. The goal is to have the stack height of the POSS® and CMG covered cells give the equivalent shielding thickness.

The BTJM string will give radiation performance of that technology and also provide a measure of inter comparison with the BTJM mounted to the UltraFlex® mesh versus the honeycomb substrate. This is not an ideal comparison because the mesh-mounted sample will benefit from radiation shielding and some thermal inertia provided by the solar array substrate holding the mesh sample. The comparison of the performance represents a "best case" comparison, but it is an interesting opportunistic comparison nonetheless.

The SLA coupon will demonstrate an 8.5X concentrator element along with the protection provided by a significantly thicker coverglass (500 microns vs. 150 microns for the BTJM string). The use of a thicker coverglass is a system level benefit afforded by the smaller cells used in concentrator systems.

With any concentrator system, solar pointing accuracy is more critical than with flat plate systems. The TACSAT-

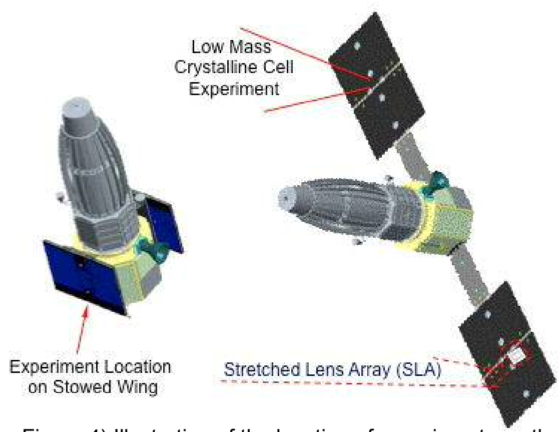

Figure 4) Illustration of the location of experiments on the Spacecraft.

4 solar array drive is designed for flat plate, but is in principle suitable for the SLA coupon. The SLA requires ±2° pointing in the critical axis and ±11° in the non-critical axis. The TACSAT-4 design will in a worst case, provide ±5° in both the critical and non-critical axes. However, pointing in the critical axis will have nominal pointing accuracy of ±1°. Therefore, we anticipate a sufficient number of measurement opportunities where the SLA will be pointed within its specifications.

STANDARD *AIAA S-122-2007*

The diagnostics of spacecraft solar arrays is usually limited to a few temperature readings and solar cell string current measurements. The added complexity, cost and general belief that the power bus is inherently predicable and reliable are primary reasons instrumentation is not put on to solar arrays. Unfortunately, these prevailing attitudes are cause for the general lack of understanding of recent solar array anomalies. The complex space environment cannot be satisfactorily reproduced on Earth to recreate many of the anomalies seen on orbit. This predicament of a lack of on-orbit instrumentation and the inability to reproduce the space environment is partially responsible for the on-orbit solar array failures seen in recent years. Recognition of the need for routine solar array diagnostics led to the creation of a new standard *AIAA S-122-2007, "Electrical Power Systems for Unmanned Spacecraft."* Spacecraft built using this standard will require solar arrays to have I-V curve diagnostics of a representative string.

INSTRUMENTATION

Part of the difficulty in implementing a requirement such as the *AIAA S-122-2007* is the non-recurring engineering costs associated with designing new circuitry for each satellite bus system. Our thought is to provide a modular, easily integrated electronics package that makes use of existing resources typically found on a spacecraft. Using just two A/D channels and 1/2 Watt from the 28V power bus, we created a radiation hard circuit using SOI technology to measure one I-V string up to 75-Watts and a shorted cell. The SOI technology is very rugged and circuits of this type may potentially be deployed on the solar array itself. However, for TACSAT-4, the measurement electronics were placed inside the spacecraft. This circuit satisfies AIAA S-122-2007 for up to a 25kW array. Two of these circuits will fly on TACSAT-4.

The circuit design uses a concept similar to the Forward Technology Solar Cell Experiment flown on MISSE-5. [iv] Using a transistor as the variable load, a modified RC circuit sweeps the solar cell through the I-V curve in about 0.4 seconds. The circuit concept is shown in Figure 5. When power is applied a 1-Hz clock applies a ramping circuit to variably bias a transistor through the solar cell load line. During the load sweep, two spacecraft A/D channels periodically (~3 ms intervals) measure the cell voltage and current to record the I-V curve. The gain stages, G1, G2 and G3 are part of the measurement circuitry and are scaled to take advantage of the voltage range of the spacecraft A/D channels.

The "off" cycle of the clock lasts about 0.1 seconds and switches in a second measurement (the shorted solar cell) to ADC1. At the same time ADC2 reads a reference voltage. A plot of the time resolved data from the flight electronics integrated into TACSAT-4 is shown in Figure 6. The circuit is implemented using Honeywell SOI technology for the majority of active parts including op amps, analog switches and regulators. The load FET is 100krad part rated to 75 Watts and can be put in parallel to accommodate higher power strings.

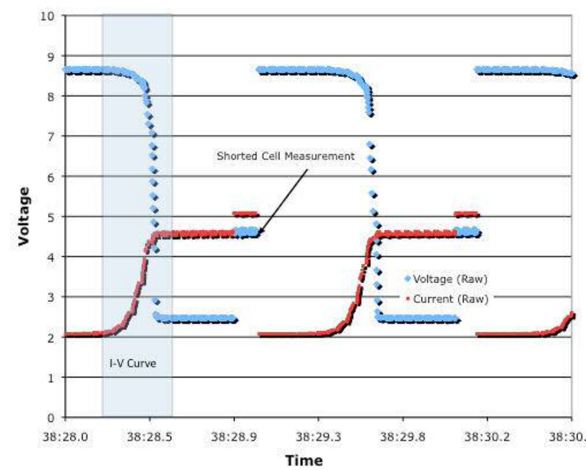

Figure 6) Plot showing the I-V sweep of a solar cell string and the shorted cell measurement.

The addition of the I-V electronics required no modification of the TACSAT software, only a change in the operating script. The two I-V circuits will effectively have 100 I-V points per curve. This data rate will provide a high fidelity I-V curve. TACSAT-4 bus will provide two temperature readings, one on each 3-cell string and the

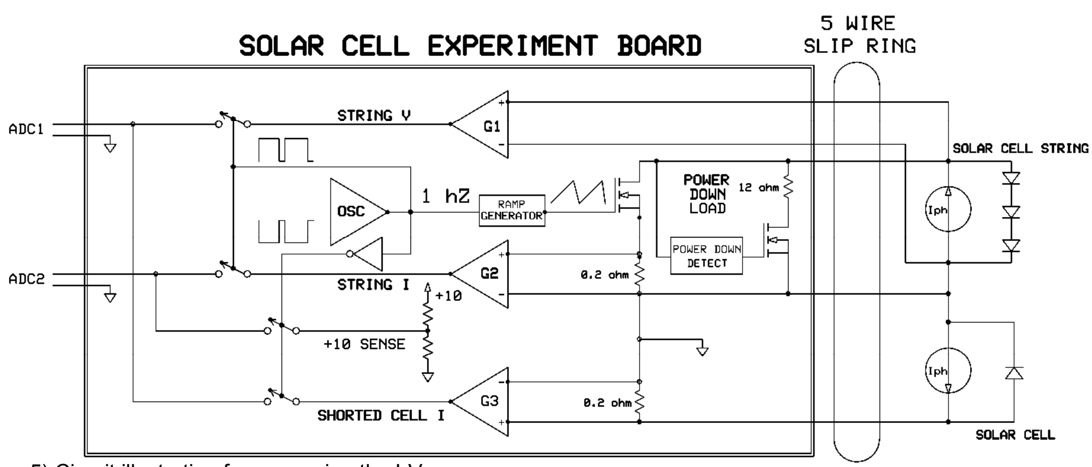

Figure 5) Circuit illustration for measuring the I-V curves.

solar array sun angle measurement.

SUMMARY

The TACSAT-4 solar cell experiment is an immediate opportunity to test advanced solar cell technologies and a simple, radiation hardened solar cell characterization circuit that can be readily adapted to most any spacecraft. The cells tested with the experiment are designed to be more efficient and more radiation hard than the current state-of-the-art and will be the first characterization of these technologies in a high radiation environment. TACSAT-4 is scheduled to launch in September of 2009.

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