ACCOMPLISHMENTS AND OBJECTIVES OF THE STRETCHED LENS ARRAY TECHNOLOGY EXPERIMENT (SLATE)

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ABSTRACT

This study presents the design and fabrication of the Stretched Lens Array Technology Experiment (SLATE). SLATE is a radiation-hardened solar array flight experiment to be flown in the Van Allen radiation belts and provide flight validation for the Stretched Lens Array (SLA). TacSat 4 is due to be launched in September, 2009 into a high radiation orbit (700 km x 12,050 km, 63.4º). This orbit will provide valuable solar cell degradation information along with proving flight validation for the Stretched Lens Array. In addition, a photovoltaic curve tracer Data Acquisition System (DAS) prototype was designed and built using a new flexible architecture. This project is part of Phase II of a MDA STTR project entitled, "Radiation-Hardened Stretched Lens Array," with Entech Solar, Inc.

INTRODUCTION

This study presents the design and fabrication of the Stretched Lens Array Technology Experiment (SLATE). SLATE is a radiation-hardened solar array flight experiment to be flown in the Van Allen radiation belts and provide flight validation for the Stretched Lens Array (SLA). The SLA experiment will fly on TacSat 4 (see Fig. 1) and consists of three SLA receiver cells (1 cm active width) with a 0.5 mm-thick ceria-doped cover glass. TacSat 4 is due to be launched in September, 2009 into a high radiation orbit (700 km x 12,050 km, 63.4º). This orbit will provide valuable solar cell degradation information along with proving flight validation for the Stretched Lens Array. The stretched lens incorporates Entech Solar's proprietary thick parquet coating, which will protect it from the effects of solar ultraviolet radiation, atomic oxygen, and low-energy charged particles.

In addition, a photovoltaic curve tracer Data Acquisition System (DAS) prototype was designed and built using a new flexible architecture. This project is part of Phase II of a MDA STTR project entitled, "Radiation-Hardened Stretched Lens Array," with Entech Solar, Inc. The SLATE I-V Data Acquisition System design was derived from the FTSCE design used aboard MISSE-5. MISSE-5 used a Motherboard and Daughter boards to obtain I-V curves. In this new approach, the Daughter board functions are split into two different functional components. The new addition is called a Load Module that can be physically distributed to various remote locations away from the Daughter board and placed wherever it best fits the application. Results of testing this design at voltages up to 130 V with a terrestrial array and its applicability to the requirements of AIAA Standard "Electrical Power Systems for Unmanned Spacecraft" (S122-2007) will be presented. The AIAA S-122 mandates taking string I-V curves and this design allows a small LM to be placed on a panel collocated with the test string. It can also be configured for wireless data transmission.

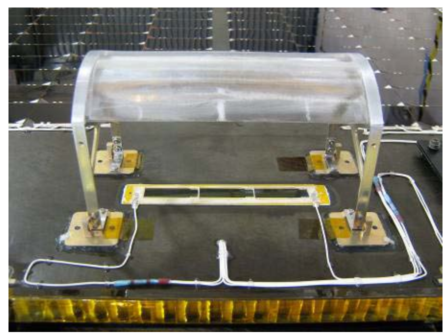

Fig. 1. SLATE-T4 Mounted on TacSat 4 Solar Array Panel

SLA BACKGROUND

The SLA developed by Entech Solar, Inc. is a space solar array that uses refractive concentrator technology to collect and convert solar energy into useful electricity. The concentrator uses a stretched Fresnel lens (8.5 cm aperture width) that refracts the incident light onto high-performance multi-junction photovoltaic cells (1.0 cm active width). SLA's unique, lightweight, and efficient design leads to outstanding performance ratings:

- Areal Power Density: > 300 W/m^2
- Specific Power: > 300 W/kg for a 100 kW Solar Array
- Stowed Power: > 80 kW/m^3 for a 100 kW Solar Array
- Scalable Array Power Capacity: 4 kW to 100's of kW's
- Super-Insulated Small Cell Circuit: High-Voltage (up to 600 V) Operation
- Super-Shielded Small Cell Circuit: Excellent Radiation Hardness at Low Mass
- 85% Cell Area Savings: Up to 75% Savings in Array $/W Versus One-Sun Array

The SLA's intrinsic design characteristics protect against electrical discharge, micrometeoroid impacts, and radiation degradation. It provides arc-free high voltage operation because the cells are fully encapsulated providing a sealed environment. The SLA is a cost effective solution with 50-75% savings in $/W compared to planar solar arrays. SLA's small cell size, which is 85% smaller than planar high-efficiency arrays, allows the cell circuit to be super-insulated and super-shielded without a significant mass penalty. Figure 2 shows a 2.5 x 5 m full scale building block module of the SLA on the SquareRigger platform (SLASR). This module is sized to produce 3.75 kW and weighs only about 10 kg.

Fig. 2. Full scale SLASR module

TACSAT 4

TacSat 4 provides an excellent opportunity to test the SLA in a high radiation environment. SLATE was originally designed to provide valuable solar cell degradation information due to the natural radiation of space along with providing flight validation for the Stretched Lens Array (SLA). These test flight objectives will be met with a flight on TacSat-4 in Fall 2009, though with some reduction in size and scope in order to meet this flight opportunity. The TacSat 4 SLA experiment will consist of a 3-cell string of EMCORE ATJM concentrator cells under an ENTECH Stretched Lens supported by ATK structure and tensioning Mechanisms. The three SLA receiver cells (1 cm active width) have a 0.5 mm-thick ceria-doped cover glass. The stretched lens incorporates Entech Solar's proprietary thick parquet coating, which will protect it from the effects of solar ultraviolet radiation, atomic oxygen, and low-energy charged particles. TacSat 4 will fly in a mini-HEO orbit of 12,050 x 700 km at 63.4 degrees inclination and it is a one year mission. The spacecraft trajectory and surrounding radiation environment can be seen in Fig. 3.

RADIATION ANALYSIS

Phase I consisted of a radiation analysis and power degradation calculations. ESA's Space Environmental Information System, SPENVIS, was used for these calculations. Radiation modeling for SLATE is threefold.

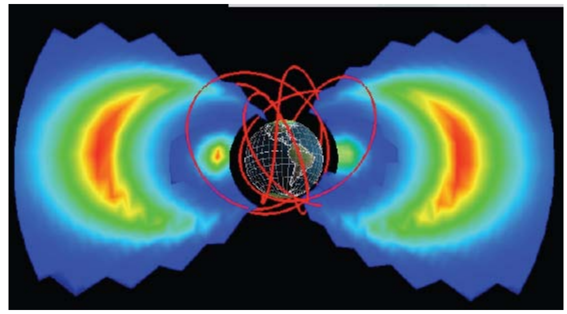

Fig. 3. Flight path of TacSat 4 in high radiation environment

First the solar cell degradation and power loss for the cells powering the experiment must be calculated to approximate the cell shielding needed to maintain sufficient power for operation. Secondly, the degradation of the experiment cells and SLA must be predicted to determine what cover glass thicknesses should be used to demonstrate various levels of cell degradation and its effects. These predictions will be used for comparison against the data acquired during flight. Finally, the radiation effects on the electronics packaging must be determined so it can be shielded appropriately to avoid failures, single event upsets, or latch-ups.

The SPENVIS model provides the 1 MeV equivalent electron radiation doses for a given orbit and duration. Losses in maximum power (Pmax), short circuit current (Isc) and open circuit voltage (Voc) are calculated as a function of protective layer thickness. This information, in conjunction with a standardized chart of power degradation of solar cells with electron fluence, allows for calculation of the power degradation of the solar cell as a function of cover glass thickness as seen in Fig. 4. SLA power degradation is only 6% for a cell with 10 mil shielding in the TACSAT 4 orbit for 1 year. The end-of-life (EOL) specific power and areal power density for the array can also be calculated. These calculations are made for both SLA and planar arrays to allow for direct comparison

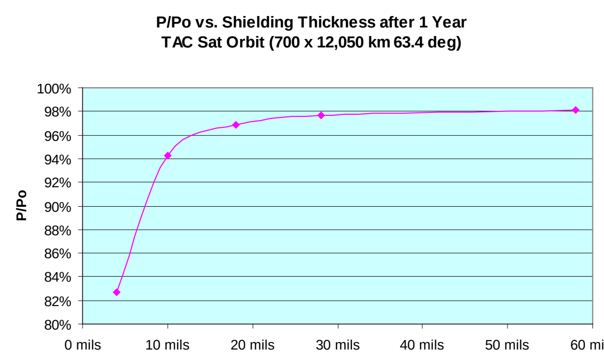

Fig. 4. Power degradation of solar cell as a function of cover glass thickness for one year in the TacSat 4 orbit.

between the two as seen in Figure 5. The SLA has a definite advantage in EOL specific power especially In high radiation orbits.

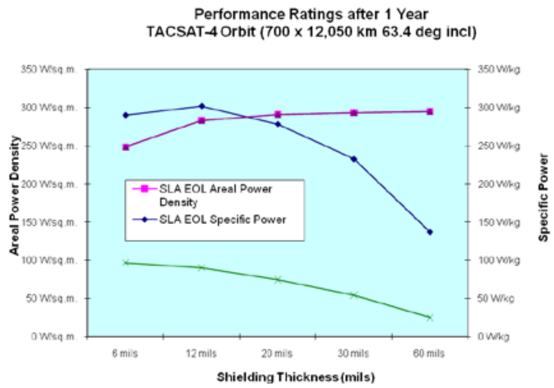

Fig. 5. EOL Specific Power and Areal Power Density comparison between SLA and planar arrays

While the initial approach for electronic design of SLATE's Data Acquisition System (DAS) is similar to that of MISSE-5 FTSCE flown on ISS, the intended orbital environment scenario is much different. The ISS orbit has a much lower radiation dose, and is primarily aimed at obtaining data on the durability of these cells to ultraviolet light and atomic oxygen exposure. Therefore is it essential to examine the radiation hardness of the electronics so they will be able to survive the high radiation orbits that will be seen with SLATE. Based on the anticipated radiation environment of this mission, the DAS box thickness required for adequate shielding to protect the motherboard and four daughter boards is 6.5 mm. This will keep the total dose below 10 kRad-Si as seen in the graph of total dose versus aluminum shielding thickness shown in figure 6. The 10 kRad-Si dose rate may still be too extreme for some of the more radiation sensitive electronics so

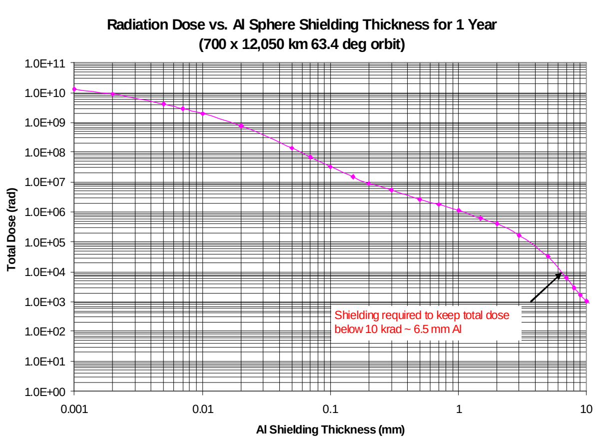

Fig. 6. Total Dose verses shielding thickness

increased spot shielding on designated parts vs. substitution for rad-hard components is being evaluated. Another approach to radiation effects mitigation is reliant upon appropriate firmware programming to develop more upset-reset tolerant software.

DATA ACQUISTION SYSTEM

The second part of the MDA project was to design and build the SLATE I-V Data Acquisition System (DAS) prototype. The development approach taken by Auburn University toward building the SLATE I-V DAS was initially derived from the FTSCE design used aboard MISSE-5.[1,2] The approach included the use of a Motherboard to: receive commands from the Host spacecraft (S/C), issue commands to and control multiple I-V tracing Daughter Boards, retrieve and save I-V trace data to memory, and relay telemetry data to Host S/C. The microcontroller Daughter Boards (DB) use analog interfaces to control multiple variable electrical loads connected to test solar cells. Auburn University revised and improved this topology and a new DAS was developed.

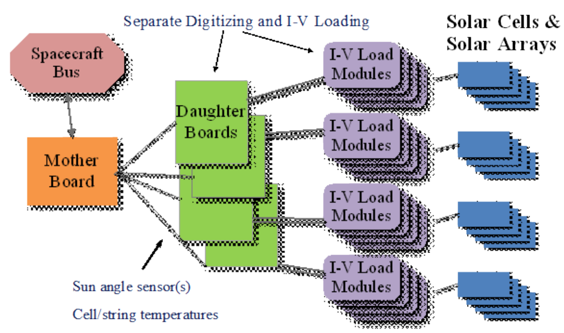

Fig. 7. SLATE's DAS new design topology

Auburn's updated SLATE DAS topology design divides the original Daughter Boards design into two different functional components. The new design topology (Fig. 7) allows the digital, microcontroller portion of the DB's to remain much the same with serial communication port connected to the Motherboard and analog control components such as ADC's (Analog-to-Digital Converter), DAC's (Digital-to-Analog Converter), and signal multiplexers. The new sub-component referred to as a Load Module (LM) is a strictly analog I-V test section which includes a variable electrical load connected to test solar cells to test solar cell arrays.

There are multiple advantages to using separate Load Modules in this modified topology. These LM's can be physically distributed to various remote locations away from the Daughter Board and placed wherever it best fit the application. In some circumstances, all may be placed in a central area near the core of the spacecraft. In other circumstance, they may best be utilized by distributing them individually to remote locations such as out on solar wing panels.

Another key advantage of this Load Module scheme is that each individual LM can be tailored to the specific solar cell or array voltage, current, and power characteristics while still maintaining identical DB interface formats. They could be designed to individually handle the role of providing a variable load for the interest of I-V curve tracing to single cells, an array string, high-voltage arrays, etc. As both the physical size and the component size of these LM's are small, such customizations are still economical. With the ability to tailor Load Modules to the specific needs and environments, this SLATE I-V DAS design can handle a diverse range of space and terrestrial applications. Sub-components of the LM's can be chosen to handle applications that range from sub-watt PV cells to high voltage, high current, and high power spacecraft PV-wing or terrestrial arrays. All this can be carried out with no modification of the DB or software.

Figure 8 shows a comparison of an I-V curve of a single triple-junction cell acquired from SLATE DAS overlaid with an I-V trace of the same cell when calibrated at NASA Glenn's PV solar calibration facility. The correlation quality of the trace is excellent. Using a different Load Module, the same unit swept 3 PV modules in series with a collective 115 Voc, 250 W (Figure 9). Another LM has handle higher voltage operation recently sweeping the 1.2 kW ENTECH SunLine array with 640 Voc.

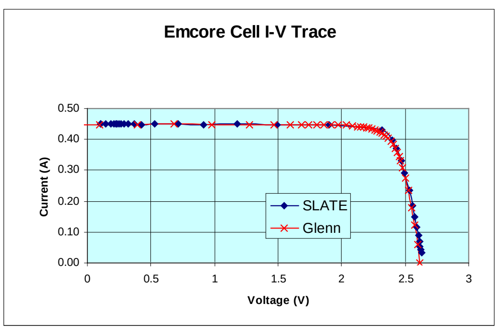

Fig. 8. I-V curve exact match to cells calibrated at NASA Glenn

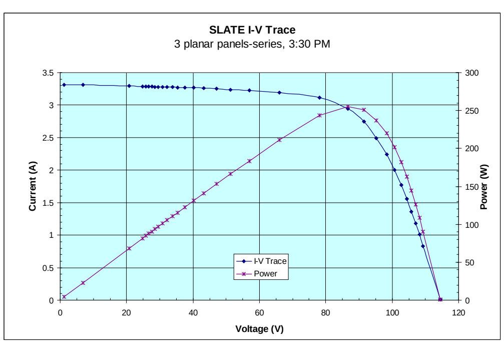

Fig. 9. I-V curve of 3 mc-Si Modules in series, 115 Voc, 250 W test.

As an additional improvement, and with an eye to supporting potential terrestrial testing applications, the DAS components were packaged with a new graphical user interface (GUI) seen in Fig. 10. The GUI consists of a programmable microcontroller with a touch-screen. The GUI sends the same command-set to, and receives the same telemetry dataset from the Mother Board allowing for easy space and terrestrial application testing and development. The unit is portable operating on 12 VDC.

The AIAA has recognized the need for more consistent and extensive electrical system monitoring. In the AIAA Standard "Electrical Power Systems for Unmanned Spacecraft" (S122-2007) recommendations have been set forth regarding functional and performance requirements as they relate to the spacecraft electrical power system (EPS). In the section entitled "Solar Array I/V Curve Measurement" it states, "I/V curve data collection capability is required, using a minimum sample of at least 0.3% cells from the solar array…" This section goes on to describe the manner in which multiple body-mounted or wing-mounted arrays are to be tested. The document recommends that at least 1 string per sub-array have I-V diagnostic capability. This is potentially an excellent fix of our design to fulfill these recommendations.

This DAS can meet the needs of space and terrestrial applications. It can also handle high voltage, current, and power operation. More comprehensive testing data will be presented in the finished paper. This paper will present the accomplishments and objectives of SLATE and will show how these advances can benefit the space and terrestrial photovoltaic community.

Fig. 10. Packaged DAS components with touch-screen GUI in a portable case.

CONCLUSION

Progress on the development and fabrication of SLATE has been presented. More detailed information on the design and testing will be available within the next year. The major benefits of the SLATE flight will be to provide valuable information on the degradation of currently-available solar cells in high radiation orbits along with proving flight validation for the Stretched Lens Array (SLA) for the entire space community. Updating the AE-8 and AP-8 radiation models is another potential benefit of SLATE.

Auburn's updated SLATE DAS topology design can handle a diverse range of space and terrestrial applications because of its ability to tailor Load Modules to specific needs and environments. The load modules can be designed to individually handle the role of providing a variable load for the interest of I-V curve tracing to single cells, an array string, high-voltage arrays, etc. As both the physical size and the component size of these LM's are small, such customizations are still economical. Also, additional DAS I-V curve tests are being carried out at higher voltages and power and will be described in the future reports.

REFERENCES

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