Stretched Lens Array Technology Experiment (SLATE)

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This study investigates the design and fabrication of the Stretched Lens Array Technology Experiment (SLATE), a radiation-hardened solar array flight experiment developed to be flown in the destructive Van Allen radiation belts. SLATE will provide valuable solar cell degradation information due to the natural radiation of space along with proving flight validation for the Stretched Lens Array (SLA).

I. INTRODUCTION

In past years, very few satellites have flown in orbits that require long durations in the Van Allen radiation belts due to the loss of power, hence lifetime, caused by the radiation. However, new advances in the design of lightweight, yet radiation-tolerant solar arrays have been made. Orbits within these radiation belts are attractive for a wide range of missions including communication, observation and resource assessment. Because the lifetime of satellites is so reduced in these orbits due to the natural radiation hazard it has not been cost effective to make major use of these orbits. This paper will discuss advances in the Stretched Lens Solar Array (SLA) and a companion flight experiment: Stretched Lens Array Technology Experiment (SLATE) that is a developmental flight experiment intended to fly in a high radiation orbit. SLATE will provide valuable solar cell degradation information along with proving flight validation for the Stretched Lens Array (SLA).

SLATE will also provide an updated validation for models such as the European Space Agency's program SPENVIS (Space Environment Information System) because the current knowledge of the radiation environment is limited. The AE-8 and AP-8 models used there are more than thirty years out of date so the potential for updated models is important to the space industry as a whole. This is a significant opportunity to gather information on how new solar cell technologies perform in high radiation environments.

II. SLA BACKGROUND

Time Frame	< 5 Years	5-10 Years
Power Capability (kW)	100	1,000
BOL Specific Power (W/kg)	330	500
Stowed Power (kW/m3)	80	120
Voltage	1,000	TBD

Table 1: SLASR properties

The SLA developed by ENTECH 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 in areal power density (W/m^2), stowed power density (kW/m^3), specific power (W/kg) and overall cost-effectiveness as shown in Table 1. SLA is an evolutionary development based on the successful SCARLET array flown on Deep Space 1, which itself was based on the Mini-Dome Lens array flown on PASP-Plus. This mini-dome lens array performed extremely well throughout a year-long mission in a high-radiation, 70-degree inclination, 363 km by 2,550 km elliptical orbit, validating both the high performance and radiation hardness of the refractive concentrator approach. The SLA's attributes match the critical requirements needed for radiation hardened satellite systems that are to be located in the Van Allen Belts. SLA's small cell size which is 85% smaller than planar high-efficiency arrays, allows shielding to be added without detrimental mass effects. Figure 1 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.

Figure 1: Full scale SLASR module

III. SLATE'S OBJECTIVES

Under Phase II of the MDA STTR project entitled, "Radiation-Hardened Stretched Lens Array," ENTECH and Auburn University are developing SLATE as a flight experiment with a dual purpose. First it will provide a space validation test of the Stretched Lens Array technology and second it will measure the performance of SLA and planar solar cells in a high radiation environment. SLATE will be a self-powered flight experiment that will be configured to allow for ease of integration with any available spacecraft that will fly in a high radiation environment.

SLATE provides a major solar cell flight test experiment in high radiation orbits allowing for comparison of SLA with tandem junction crystalline cells as well as current thin film cells. A preliminary, notional design is shown in Figure 2. One half of each panel is devoted to the SLA experiment and the other half of each panel is devoted to one-sun cells, half of which provide power for SLATE and the other half of which are one-sun cell experiments, including both crystalline cells and thin-film cells with different types and amounts of shielding. Full I-V curves will be measured to determine cell degradation. Electronics used for I-V curve acquisition will use an electronic design approach similar to that used on Forward Technology Solar Cell Experiment (FTSCE) which recently flew successfully on ISS with the MISSE-5 experiments.[1,2] Additional shielding and radiation hardening by design of the electronics is necessary for SLATE due to the high radiation, proton rich orbits that are anticipated. Auburn is using a modular design approach for both hardware and firmware for this experiment. Pending decisions based on the radiation analysis, testing and evaluation, and the cost of radiation hardened components, the design will continue to evolve.

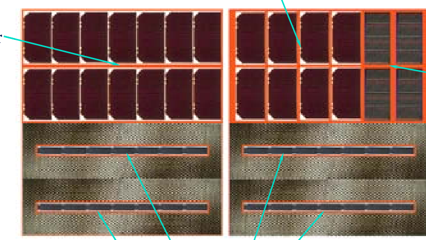

Figure 2: Preliminary Design of SLATE

IV. RADIATION MODELING:

Radiation modeling for SLATE is threefold. 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. SLATE will also provide an updated validation for models such as ESA's SPENVIS because the current knowledge of the radiation environment is limited. The AE-8 and AP-8 models used there are more than thirty years out of date so the potential for updated models is important to the space industry as a whole.

Currently the flight spacecraft has not been selected so the specific orbit is unknown, yet SLATE can be optimized to fly in any orbit. Once a host satellite is determined and the orbital parameters are known, an analysis of the radiation environment for that specified orbit can begin. In preparation, a high radiation, proton dominated orbit of 6000 km perigee and 12,000 km apogee has been chosen as an example. To understand and compare the various radiation environments for these orbits, simulations have been run using SPENVIS and the data has been graphed. The natural radiation environment in space is defined by existing models, such as AE-8 for trapped electrons and AP-8 for trapped protons in Earth's radiation belts, and JPL models for solar protons. SPENVIS incorporates these models in an online analysis program package. The SPENVIS model provides the 1 MeV equivalent electron radiation doses for given orbits and durations. 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 Figure 3 for our chosen 6000 km by 12000 km orbit for various inclination angles. The end-of-life (EOL) specific power for the array can also be calculated. These calculations are made for both SLA and planar arrays to allow for direct comparison between the two as seen in Figure 4. SLA is more than 3X better at 1 year and that increases to 4X at 10 years. Areal power density can also be compared as seen in Figure 5 where the heaviest SLA is compared with the lightest planar array. This is not even a straight apples-to-apples comparison since the heaviest SLA is 14% lighter than the lightest one-sun array but SLA's advantage over planar is obvious, especially on longer missions.

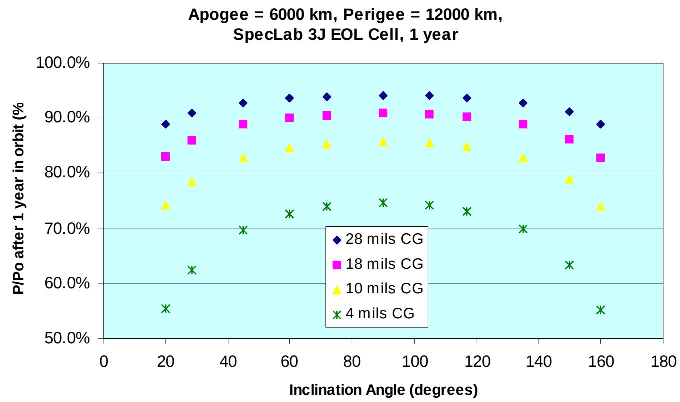

Figure 3: Power degradation of solar cell as a function of inclination angle and cover glass thickness

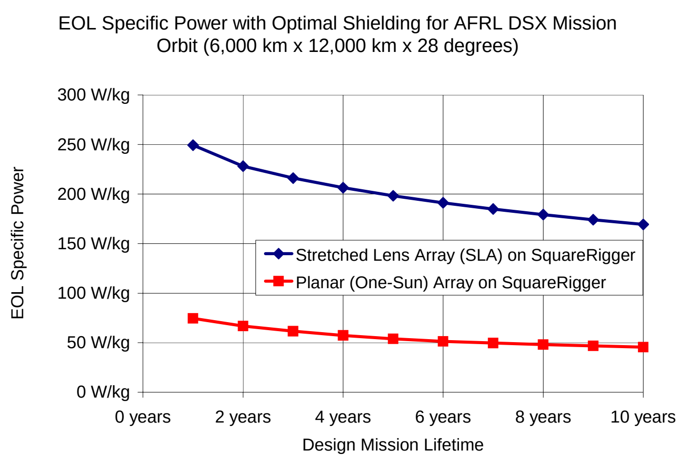

Figure 4: EOL Specific Power Comparison

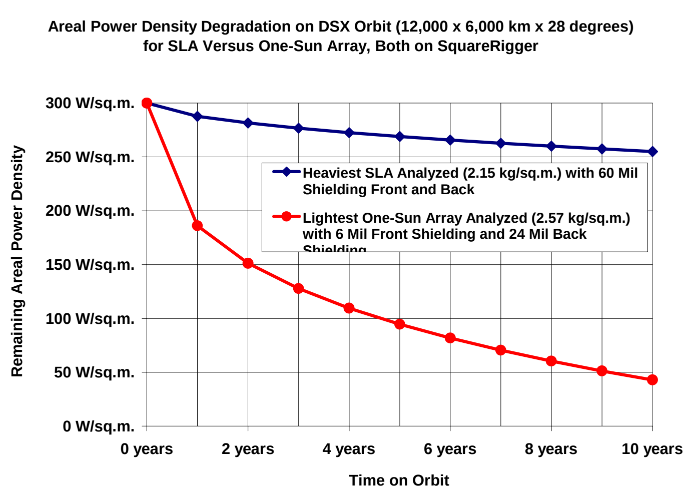

Figure 5: EOL Areal Power Density Comparison

As mentioned above, 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. Radiation hardness of the DAS electronic components Auburn is planning to use is being evaluated for the radiation shielding requirements for an AFRL DSX mission. This mission is an example high-radiation and candidate orbit for the host spacecraft. Auburn has also initiated test plans to conduct gamma ray dose radiation on SLATE prototype electronics using this prototype daughterboard design to evaluate components selection and shielding for these high radiation mission orbits. Auburn is also designing these tests within the context of ELDRS (Enhanced Low Dose Radiation Effects), which has shown an originally non-intuitive degradation effect at these lower dose rates. Based on the anticipated radiation environment of DSX and the gamma ray tests, the DAS box thickness required for adequate shielding to protect the motherboard and four daughter boards will be determined. SPENVIS modeling of the DSX orbit scenario indicates that a 7mm Al wall thickness will result in a 10 kRad-Si total dose 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 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. Maximum dose rates are being studied now and applied to the gamma ray test planning.

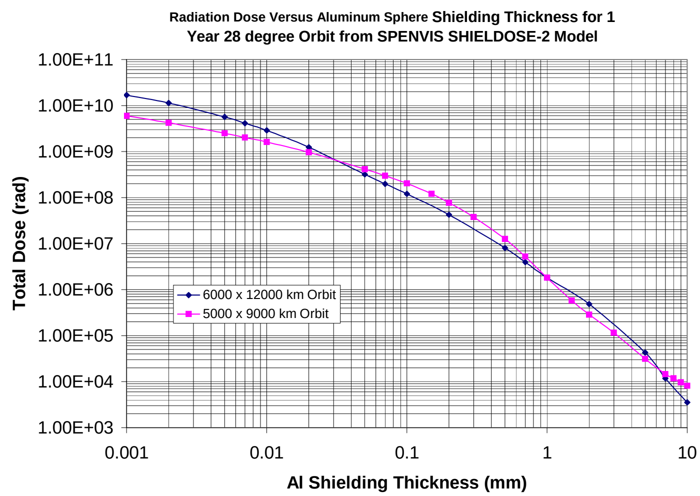

Figure 6: Total Dose verses shielding thickness

V. 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. The next step is finding a flight.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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