Ex Ordo Abstract #028

ROSA and Solar Cell Module Combined Environments Test Plan

Kenneth H. Wright, Jr.[1], Bao Hoang[2], Todd A. Schneider[3], Jason A. Vaughn[3], Patrick Lynn[3], Peter F. Bertone[3], Ira Katz[4], David T. Frate[5], Jeffrey S. Hojnicki[5], Jeremiah McNatt[5], and Brandon T. Klefman[5]

[1]Universities Space Research Association – Science and Technology Institute, Huntsville, Alabama USA
[2]Maxar Space, LLC, Palo Alto, California USA
[3]NASA, Marshall Space Flight Center, Huntsville, Alabama USA
[4]Consultant, Pasadena, California USA
[5]NASA, Glenn Research Center, Cleveland, Ohio USA

***Abstract*— Roll-out solar array (ROSA) technology is an emerging component of the future of spacecraft photovoltaic power subsystems. Qualification and risk reduction testing are necessary to demonstrate design worthiness for spaceflight implementation of the array and solar cell modules. Maxar Space LLC and NASA have undertaken a rigorous combined environment (CE) test campaign for a ROSA design expected to be a part of the Power and Propulsion Element (PPE) for the NASA Gateway which will be an outpost orbiting the Moon. The CE tests consist of several simulated space environment exposures associated with the planned mission: UV radiation, electron/proton radiation, xenon ion plume exposures, and vacuum thermal cycling and electrostatic discharge (ESD). These tests are conducted on small coupons consisting of the planned ROSA flight elements, and all tests are performed at the NASA Marshall Space Flight Center. This paper discusses the test plan, requirements for each environment, and the functional testing performed. Of note is a new approach for the induced primary arc used in the ESD testing, which better simulates the plasma expansion during the ESD event. Progress on executing the test plan is presented.**

I. INTRODUCTION

Photovoltaic array technology has evolved from the aluminum honeycombed substrate to basically a Kapton-sheet based substrate. This new configuration is called Rollout Solar Array (ROSA) and has recently been tested in space on the International Space Station (ISS) in 2017. Deployable Space Systems (DSS), now owned by Redwire, fabricated a ROSA test section that operated for one week on the ISS. Fig. 1 shows a picture of ROSA on ISS in 2017. In June 2021, two new ROSAs were installed on ISS to provide future power to the facility.

Maxar Space LLC (Maxar) is teaming with Redwire/DSS to produce a ROSA system for the Power and Propulsion Element (PPE) of NASA's Gateway spacecraft. Fig. 2 shows an artist conception of Gateway with an approaching Orion spacecraft. Gateway will be in a Near-Rectilinear Halo Orbit (NRHO) around the moon. The PPE ROSAs will provide 55.5 kW of power at Beginning of Life (BOL).

This paper describes the details of the space environments effects test plan to reduce risk for the planned ROSA Gateway PPE design.

Fig. 1. ROSA deployed on ISS in 2017. Picture credit: iss052e002865.

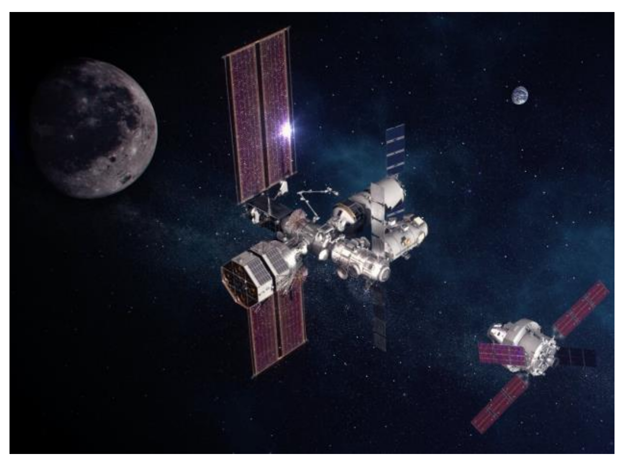


Fig. 2. Artist depiction of Gateway with approaching Orion spacecraft. Credit: NASA-JSC-51670047958_9323e6ad71_h

II. TEST PLAN

A. Space Environments

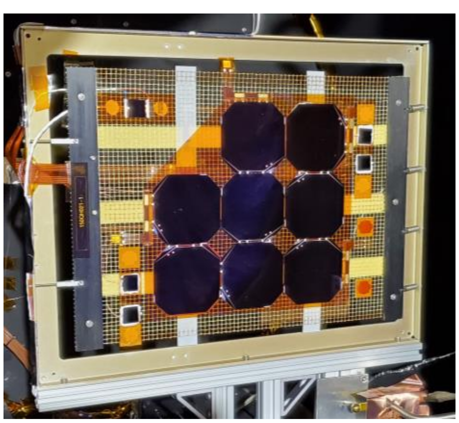
To provide for sufficient risk reduction information about the ROSA design, testing must occur in as many relevant space environments as possible. These environment fluences are calculated and tailored for the spacecraft (Gateway) mission. Gateway will utilize Hall thrusters to move itself from low earth orbit through the radiation belts to the NRHO. The nominal mission lifetime is 15 years. The test plan is divided into three cumulative segments: Earth Orbit Raising (EOR), EOR plus 5-year, and EOR plus 15-year. Given the slow passage through the radiation belts (nominally 460 days), the delta fluence in each of the three segments will not be the same. Table I below shows the cumulative fluence for each environment at the end of each mission phase. Each environment listed in Table I has its own specialized test chamber. This test approach has previously been discussed in Wright et al., 2012.

At the beginning of the test campaign and after each simulated environment, a series of functional tests are performed. These tests include 10x magnification inspection, Large Area Pulsed Solar Simulator (LAPSS), Dark-IV, By-pass diode, electrostatic discharge (ESD), Forward Bias (FB) and Reverse Bias (RB) of each component of the diode board.

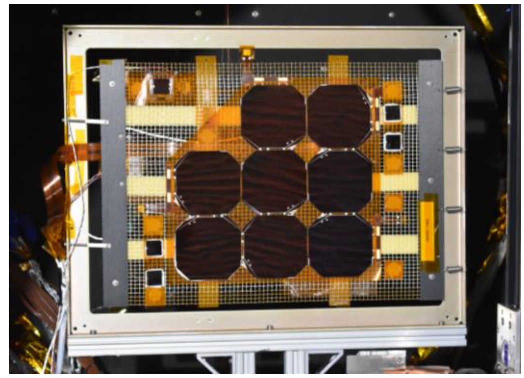
B. Coupons

Chamber dimensions dictate that only coupon-size test articles can participate in this test campaign. Each test coupon contains elements anticipated for the PPE flight design. Two configurations of electrically active coupons that contain 65 cm^2 Z4J cells integrated with an array blanket mesh and frame participate in the test program. The cell array on two coupons contains two strings while a third coupon contains three strings. Cables are included to allow electrical connection to each string. The solar cell cover-glass is 100 microns thick. The cover-glass material is Qioptiq CMG with single layer MgF_2 anti-reflective coating. In addition, one diode board coupon is part of the test plan. Fig. 3 shows each test coupon.

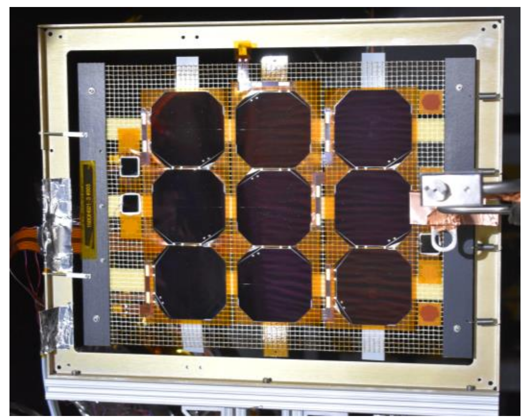
a.



b.



c.



d.

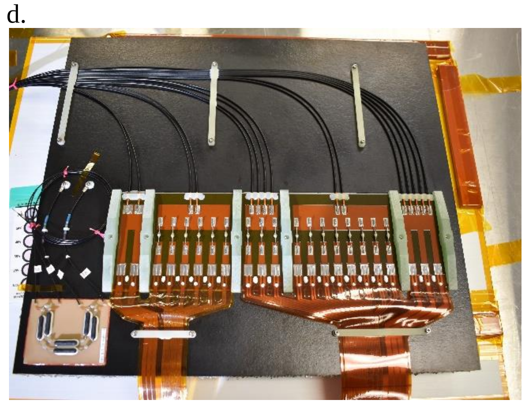


Fig. 3. Photographs of test coupons. a. CE-1. b. CE-2. c. CE-4. d. Diode Board. CE=Combined Environment. Picture Credit: NASA-MSFC Todd Schneider.

C. ESD Test – Primary Arc

The ESD test is conducted in the same manner and employs a similar circuit as was discussed in Wright et al., 2012. The Primary Arc (PA) circuit has changed due to our evolved understanding of nature of this arc. The derived PA amplitude as determined in Wright et al. (2012) from the so-called perimeter theory was 28 A for an arc inception voltage (AIV) of 2000 V. This large PA amplitude has not been observed in ground testing performed on large panels in Japan, Europe, or USA. Recently, a new PA theory, based on a self-consistent multi-species spherical plasma expansion, was published by Katz et al., 2021. The Katz et al., 2021 theory was compared to results from the Okumura et al., 2012 experiment results with very good agreement. The Katz et al., 2021 approach was used to determine a PA pulse for the PPE coupon testing. With an average value of 2000 V from AIV testing of the three cell coupons, the PA amplitude is predicted to be a little over 5 A. For the Beginning-of-Life (BOL) test on the coupons and due to the limited selection of electrical components for the PA pulse forming circuit, the amplitude of the PA was 4.6 A. Fig. 4 shows the representative PA pulse used in the BOL test. For future ESD tests within the Test Plan, we may adjust the PA circuit to achieve an amplitude closer to 5 A.

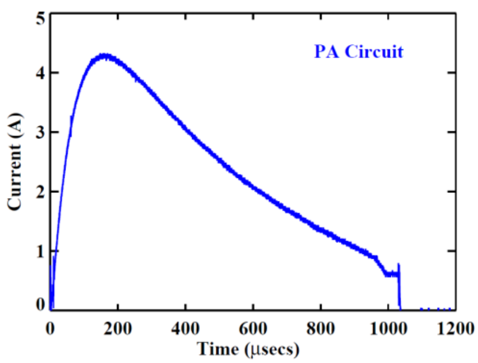


Fig. 4. Resulting Primary Arc from the pulse-forming circuit used in the BOL ESD test. PA pulse shape motivated by Katz et al., 2021.

III. Test Plan: Results to Date

As of this moment, the current place in the test campaign listed in Table I is just before the Ion Erosion Test. No sustained arcs were observed in the BOL ESD test. LAPSS testing has revealed a small decrease in the short-circuit current of the cell strings following the Earth Orbit Raising (EOR) mission phase radiation test. Fig. 5 shows a plot of the CE-4 String 1 cumulative results. The average degradation of the 7 strings from all three coupons is -3%. The average predicted degradation is -2.7%. It is noted that 52% of the End-of-Life cumulative electron radiation is achieved by the end of the EOR mission phase. This is due to the use of Hall thrusters to boost the PPE from low earth orbit to the lunar NRHO orbit.

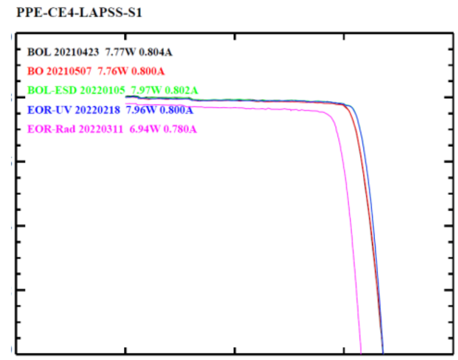


Fig. 5. Summary LAPSS data of CE-4 String 1 through the EOR radiation exposure. Each LAPSS data set is overlaid. The labels indicate the point in the test campaign sequence, date of LAPSS test, maximum power value, and short circuit current. Axis labels deliberately omitted due to proprietary concerns.

IV. Summary

The PPE ROSA risk reduction test campaign is well underway. All solar cell module coupons have completed EOR radiation and are in EOR ion erosion test. The diode board in currently undergoing the BOL ESD test. Completion of the test campaign is expected by May 2023.

Acknowledgment

K.H.W. acknowledges support from MSFC-USRA Cooperative Agreement 80MSFC17M0022.

References

Katz, I., B. Hoang, and K. Toyoda, “Multicomponent plasma expansion model for arc discharges on large-area solar arrays,” J. Spacecr. Rockets, on-line Pub. Date 9/29/2021. https://doi.org/ 10.2514/1.a35163

Okumura, T., M. Imaizumi, K. Nitta, M. Takahashi, T. Suzuki, and K. Toyoda, “Flashover discharge on solar arrays: analysis of discharge current and image,” J. of Spacecr. and Rockets, vol. 48, no. 2, pp. 326–335, May 2012. https://doi.org/10.2514/1.50907

Wright, K., T. Schneider, J. Vaughn, B. Hoang, V. Funderburk, F. Wong, and G. Gardiner, “Electrostatic discharge testing of multijunction solar array coupons after combined space environmental exposures,” IEEE Trans. Plasma Sci., vol. 40, no. 2, pp. 334-344, Feb. 2012.

TABLE I. SPACE ENVIRONMENT DEFINITIONS AND MISSION PHASE FLUENCE

Cumulative Space Environment Exposure after each mission phase			
Environment Type	***EOR***[a]	***EOR+5y***	***EOR+15y***
UV radiation in Equivalent Sun Hours (Front)	667	1333	2000
1 MeV electrons in 10^{14} #/cm^2 (Front & Back)	6.24	8.4	12.1
40-50 keV protons in 10^{15} #/cm^2 (Front & Back)	2.0	4.6	9.8
580 eV xenon ions in 10^{19} #/cm^2 cells (Front & Back)	1.35	1.4	1.5
580 eV xenon ions in 10^{18} #/cm^2 diode board (Front only)	8.43	8.75	9.37
vacuum thermal cycling at +100 C to -183 C (Front & Back)	268	318	418
electrostatic discharge (ESD) # of arcs (Front only)	12[b]	18	24

[a.] EOR = Earth Orbit Raising

[b.] includes 6 arcs at Beginning-of-Life