RADNEXT Transnational Access Summary Report

Project title	*SEU detection test for ScOSA Flight Experiment (SEU ScOSA FE)*
Project TA identifier ***Example: TA1-11 (1st TA call, experiment 11)***	*TA08-249*
General application ***(e.g. space, high-reliability ground level, avionic, high-energy accelerators and others)***	*space*
Type of test ***(e.g. SEE, TID, TNID, radiation monitor calibration and others)***	*SEE*
Group leader, Institute	*Daniel Lüdtke, DLR-SC (daniel.luedtke@dlr.de)*
Date(s) of the experiment	*2023-10-09 to 2023-10-13*
Facility	*PSI*
Amount of access granted (unit of access: 1h)	*24h*

Objectives of the experiments

(This can be a summary of the proposal that may also include the reasons for choosing the beam and the motivation behind the use of the specific test vehicles)

The goal of this project is to validate a detection software for Single Event Upsets (SEUs) which is one of the key applications of the “ScOSA Flight Experiment” project [1]. The project aims to demonstrate DLR’s On-Board Computer architecture ScOSA (Scalable On-board Computing for Space Avionics) in-orbit in a flight mission scheduled for 2024 [2].

The SEU detection application is designated to obtain the SEU rates of a Commercial-off-the-shelf (COTS) DDR-RAM component during the operation in space and to improve the systems overall reliability. The objective of the radiation test of the SEU application is not only to validate its functionality but also provide a reference point for the measurements that will be conducted in-orbit.

The objective is to contribute to the following scientific and technical objectives:

- Validating the SEU detection application: This test will help to validate that the current implementation of the SEU detection application meets the scientific requirements of the SCOSA Flight Experiment project.
- Obtaining ground reference data to validate in orbit experiment results: This test will help to obtain the necessary ground reference data to analyze and validate the in-orbit results. During the in-orbit experiment, there is little to no control over the external variables and the

observability of the system is very limited. Therefore, results from this controlled environment are relevant to the research process.
- Comparing the rate of particles vs. rate of SEUs: This test will help to understand the relation between the rate of SEUs under different conditions, such as energy levels, for the target hardware. This information is relevant to understand the in-orbit experiment results. It also provides a baseline for evaluating the SEU measurements in-orbit under different environmental conditions.

Relevant publications

[1] Daniel Lüdtke, Thomas Firchau, Carlos Gonzalez Cortes, Andreas Lund, Ayush Mani Nepal, Mahmoud M. Elbarrawy, Zain Haj Hammadeh, Jan-Gerd Meß, Patrick Kenny, Fiona Brömer, Michael Mirzaagha, George Saleip, Hannah Kirstein, Christoph Kirchhefer, Andreas Gerndt (2023) **ScOSA on the Way to Orbit: Reconfigurable High-Performance Computing for Spacecraft**. *2023 IEEE Space Computing Conference (SCC)*, Pasadena, CA, USA, 2023, pp. 34-44, doi: 10.1109/SCC57168.2023.00015
https://elib.dlr.de/196642/

[2] Lund, Andreas und Haj Hammadeh, Zain Alabedin und Kenny, Patrick und Vishav, Vishav und Kovalov, Andrii und Watolla, Hannes und Gerndt, Andreas und Lüdtke, Daniel (2021) **ScOSA system software: the reliable and scalable middleware for a heterogeneous and distributed on-board computer architecture**. CEAS Space Journal. Springer. doi: 10.1007/s12567-021-00371-7
https://elib.dlr.de/142681/1/Lund_et_al-2021-CEAS_Space_Journal.pdf

Experiment test report

(Please give an outline of the experiment, e.g., a brief description of the measurements made, initial analysis and results, and whether your objectives have been achieved. This is likely to be a preliminary assessment of your experiment whilst data analysis is ongoing. You are **encouraged to include any initial figures, data plots or tables summarizing your results**. You can make this as long as you would like, but around two sides is a guide.
Given the **RADNEXT open data research frame** you are also expected to include information related to device references, date codes, serial numbers, wafer lot numbers and technology processes, whenever these information are available, in order to boost the radiation response traceability throughout the project. Test conditions are equally as important, therefore, quantities such as bias conditions for the various samples, electrical measurement characterization before and after the test, dose rate or particle fluxes and measurements upon annealing are also expected to be included.)

Test setup and conditions

The tests were carried out on hardware designed for high performance computing purposes of the ScOSA flight experiment. The custom-made PCB consists of a Xilinx Zynq 7020 SoC, two Micron MT41K256M16TW-107 DDR3 memory modules of 500 MB each and various components for power supply and health monitoring purposes.

Since the focus of the tests relied on the behavior of the two DDR3 modules only, the test setup was arranged accordingly. The center of the square-cut beam was placed exactly so that only the memory modules were exposed to the beam directly. Due to the circumstances on-site, the setup was built on a mounting plate that could directly be fit into the dedicated holding mechanism. With this arrangement the device was placed in front of the beam with a distance of 60 mm, which was the closest possible distance.

In order to control the device under test (DUT) and to establish data connection during the test, a computer was placed near the test setup. The computer was connected to the power supply to turn the test setup power on and off, the DUT via a RS 422 interface for data exchange with the Zynq and the control room via network to establish remote access.

Description of measurements

The application used for this experiment implements the monitoring of a memory area with adjustable size, implementing redundant, self-repairing reference values and reporting mechanisms based on the design specification of the ScOSA system, including a heartbeat signal and error messages for different error cases. It was running in a software setup where it was automatically restarted in case of failure. The memory area monitored in the experiment was 900 MB, which was the maximum available area considering the operating system, the ScOSA middleware and some margin.

After some calibration, it was decided to test at a flux of 1e6 particles/cm^{2}s, as that was a flux at which we saw a significant number of events, but not too many system crashes to make the experiment unusable. The tests where conducted at different energy levels between 30 and 230 MeV, where a consecutive test run was conducted for one hour per energy level.

Preliminary results

The analysis of the measurements is still ongoing, but the first preliminary results indicate that the objectives of the experiment could mostly be fulfilled.

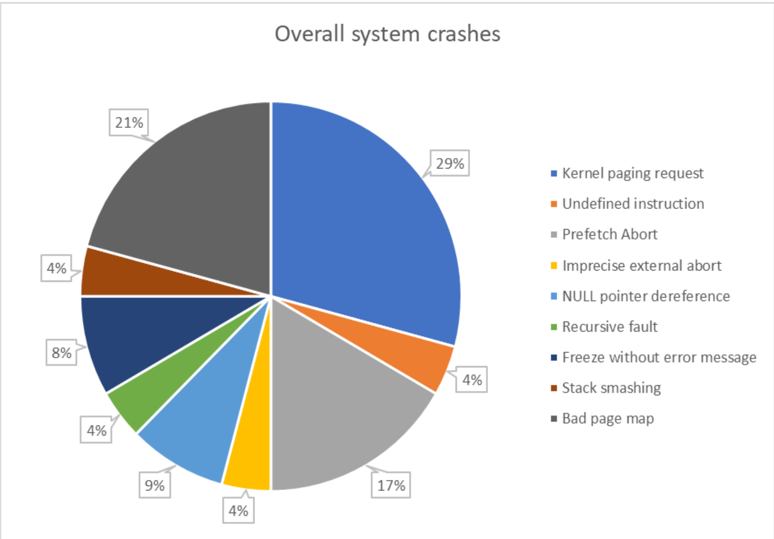

Figure 1: Different types of system crashes monitored across all energy levels

First of all, it demonstrated the overall functionality of the application and its capability to monitor SEUs. It also identified possibilities for improvement of the implementation, especially regarding communication of the measurement results.

An interesting, albeit unexpected find was the high vulnerability of the Zynq SoC that was not placed directly in the beam. Apart from the expected single events in the memory, the amount of system crashes presumably caused by stray particles was significant. That gave us a chance to additionally collect data about the types and frequency of system crashes as seen in *Figure 1*. There were 24 observed system crashes in total, where, if the same error triggered two crashes, it was only counted once.

The number of measured SEUs is depicted in *Figure 2*, as it was extracted from the raw data. This data still needs to be processed, as it still includes the occurrences of SEU bursts, which are likely caused by a fault in the memory controller and therefore need to be counted as SEFIs, not SEUs.

As the facility provided the details regarding fluence and dose during the test runs, the reference data for the flight mission can be calculated, as well as the relation between the number of particles and the number of SEUs on the analyzed system. Both of these evaluations are ongoing.

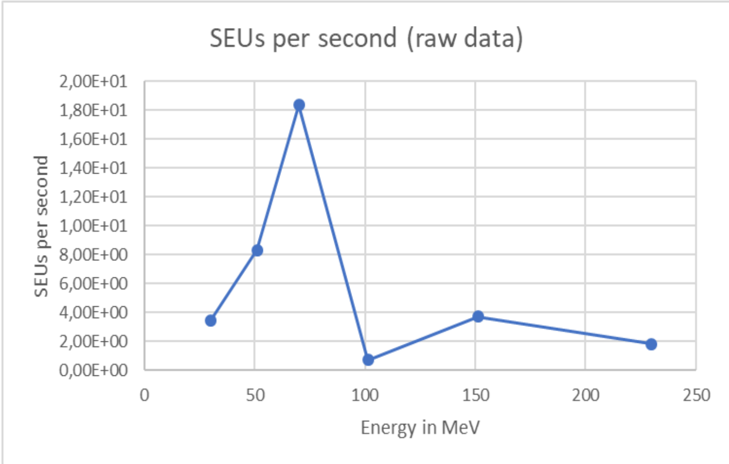

Figure 2: Preliminary number of measured SEUs per second without removing bursts that should be counted as SEFIs

Discussion on preliminary results

As described before, the data processing and evaluation is still ongoing. Still, some of the results can already be discussed.

First of all, the different types of system crashes give a good overview on the types of errors that can be expected in a radiation environment. Even though the different types are not surprising themselves, the overview shows the variety of impacts that single event effects can have on a complex software system. This is also important to be aware of the different kinds of behavior that need to be dealt with in an onboard software system for a space mission, as different kinds of errors might require different measures to mitigate them.

An interesting observation that is still being analyzed is shown in *Figure 3*. While the system crashes show a significant outlier around the 50-70 MeV area, the SEU peaks noticeable in the same region. This could be attributed to the SEFIs mentioned earlier that appeared as SEU bursts. On the other hand, the outlier could also be the high starting value of the system crash cross section. This needs to be clarified in further evaluations.

Outlook

Apart from the ongoing evaluations mentioned throughout the report, the publication of the final results is also planned. Moreover, as mentioned in the objectives, the measurements will provide a baseline for comparison of the in-flight data.

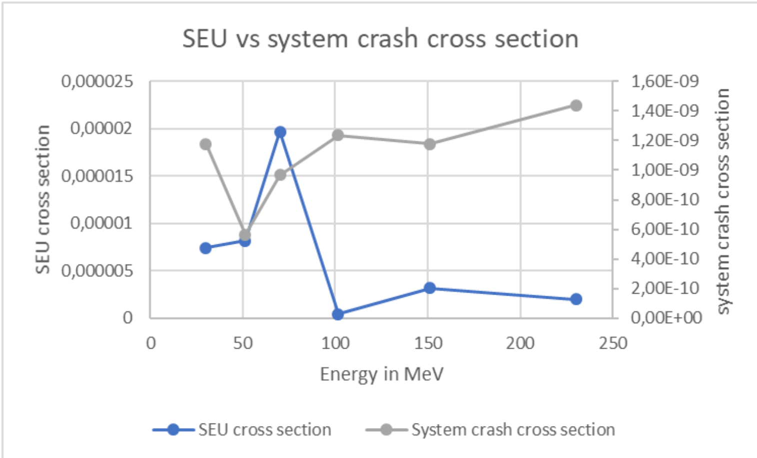

Figure 3: Comparison of SEU and system crash cross section

Furthermore, the radiation test has proven useful in the evaluation and improvement of the software. In the consequence, it has been made more robust and the communication has been adapted to be able to handle huge amounts of data in SEFIs.

Therefore, further test campaigns for the ScOSA system itself and other software mitigation techniques are being discussed.

Outcome of the experiments

Please indicate what the experiment is likely to lead to by putting an 'X' next to one or more of the possible outcomes below.

Journal publication	X
Data for Thesis	X
Follow-up experiment at same facility	X
Follow-up experiment at another facility	X
Other	

User feedback

(Please indicate any particular issue encountered or any suggestion you may have for improvements in the RADNEXT TA lifecycle. This may cover any aspect: proposal management, communication, beam assignment, user support before, during and after the test.)

First of all, we would like to thank all the people in the RADNEXT program for the opportunity to test our experiment. A special thanks to the PSI team and the operators, who did not only support our measurements, but also answered a lot of questions from a team without much radiation test experience. The results are very valuable for the project and also the PhD Thesis of one of the researchers.

Moreover, the proposal management and beam assignment worked without any flaws. Only the planning could have been smoother if the communication before the test campaign would have been better.

As a RADNEXT user, we encourage you to submit the scientific results of your experiments to journals as well as to the NSREC and RADECS data workshops. Please remember to include the RADNEXT acknowledgment into your publications!

RADNEXT acknowledgment:

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