Deliverable D32

ESA contract 19384/06/NL/JA

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<th>Number</th>
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<th>Document ID</th>
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<tbody>
<tr>
<td>AD01</td>
<td>HAS2 detailed specification</td>
<td>APS2-CY-FOS-06-004</td>
</tr>
<tr>
<td>AD02</td>
<td>HAS2 evaluation test report</td>
<td>HAS2-CY-FOS-07-005</td>
</tr>
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</table>
1 Introduction

1.1 Scope
This document details the work performed by Cypress Semiconductor and its subcontractors under ESA contract number 19384/06/NL/JA.

After an introduction (section 1), the report discusses the management of the project (section 2), phase 1 and phase 2 of the project (sections 3 and 4) and lessons learned (section 5). Section 6 contains the conclusions.

1.2 Objectives
The objectives of this project were to perform whatever design updates were considered necessary to go from a prototype to an FM design and to complete a full evaluation of the resulting FM HAS image sensor and file an application for EPPL entry.

The existing HAS sensor has been developed in the past under ESA contract 17235/03/NL/FM. The sensor was developed specifically for star tracker applications. The sensors have been characterized in the framework of the respective ESA contract for performance under nominal conditions. Multiple new star tracker developments in the European Space Industry have baselined the use of this detector and are depending on the evaluation campaign to demonstrate the suitability of the HAS for space applications. In order to secure the central role for AOCS applications of APS sensors generally, and of HAS specifically, it is required to perform a complete evaluation in order to demonstrate its suitability for space use.

1.3 Company background

FillFactory became operational on January 1st, 2000 and is active in the field of CMOS image sensor development and production. FillFactory is considered to be one of the leading companies in the field of CMOS image sensor development for professional, industrial and scientific applications for the following markets:

- Industrial vision
- Digital Photography
- Medical applications
- Space and Military applications


In August 2004, FillFactory was acquired by Cypress Semiconductor and merged into Cypress Semiconductor Corporation Belgium BVBA (CSCB). CSCB currently employs 75 highly qualified people that work on design, characterization, product engineering, test engineering, qualification and testing of image sensors.

CSCB is active on a worldwide scale with major customers in the US, Japan and Europe. CSCB has already successfully developed a number of CMOS image sensor devices that are currently implemented in a wide range of products. These developments include large area, large resolution and very high frame rate CMOS image sensors, as well as very small area and resolution sensors.

FF/Cypress is recognized as center of expertise for CMOS image sensors for space applications. The work for ESA was triggered by the development of the so-called Visual Telemetry System (VTS) in cooperation with MMS and DSS/OIP. The VTS camera was developed around the FUGA15 image sensor. The VTS system was successfully flown on the TEAMSAT mission launched by the ARIANE502. On overview of all past and running ESA CMOS image sensor projects is given below:

As IMEC staff:
1.4 Space heritage

The following detector products have been developed by Fillfactory/ Cypress and have already flown.

- FUGA15 on TEAMSAT [monitoring camera]
- IRIS1 on PROBA [monitoring camera]
- IRIS1 on MARS EXPRESS [monitoring camera]
- ACE for Canadian Space Agency [sun observation camera]
- STAR1000 on Rockviss (ISS) [monitoring camera]
- STAR1000 on Columbus [sun sensor in payload]
- STAR250 on TacSat2 (Roadrunner) [combined star tracker/mems gyro]

1.5 Confirmed missions

Cypress APS detectors are included in several AOCS products which, at the time of writing, had been selected to fly on the following missions:

- Payloads:
  - PROBA2:
    - HAS based star tracker (demonstrator)
    - STAR250 based sun sensor (demonstrator)
    - HAS based extreme-UV sun camera (scientific payload)
  - Alphasat: STAR1000 base star tracker
  - 2 LEO missions: LCMS based star tracker
- STAR1000 based sun sensors:
  - Lisa Pathfinder
  - GOCE
  - Sicral
- STAR1000 based star trackers:
  - OHB Small Geo: 2 per platform
HAS2 based star trackers:
- Alphabus
- Prisma
- Bepi Colombo
- Astro-G
- Smart-Olev
- Sentinel-1
- Sentinel-3

1.6 HAS2 sensor overview

The HAS sensor has been processed in the 0.35 µm 1P3M XFAB technology. The HAS assembly is performed in a dry nitrogen environment using a 84 pin JLCC ceramic package with a 1.5mm AR coated BK7G18 radiation hard glass lid.

- The main driver for the choice of lid material is the radiation hardness and the thermal expansion. The increase in the glass lid thickness – in comparison with the 1mm glass thickness used for the STAR-1000 device – for the HAS is to minimize the deflection due to exposure to vacuum.
- A semi-hermetic package approach (glued glass lid) was chosen over an ‘open sensor’ approach because a semi-hermetic approach allows to guarantee the cleanliness of the sensor over long time, including during screening of flight sensors. It also eases handling and storage and therefore allows a lower overall sensor cost.
- The cavity is filled with dry nitrogen. The main driver for this is to minimize the moisture level inside the cavity and ensure a neutral, non-corrosive environment.

![HAS device construction](image)

*Figure 1. HAS device construction*

The HAS features a 1024 x 1024 array of 18 micron pixels with a dual addressable y shift register for rolling shutter operation, programmable gain and offset amplifier and an on chip 12 bit pipelined ADC. A new feature added to the HAS, specifically to improve performance, is the support for non-destructive readout, i.e. the pixel is reset and readout independently with readout leaving the original pixel signal unaffected meaning it can be read several times while still integrating (Figure 2). This mode of operation opens up two primary new opportunities for the user: correlated double sampling (the recording and later removal of the initial ‘empty’ level which effectively removes reset noise and FPN) and the ability to have different usable effective integration times within a single frame to extend the dynamic range by continuously reading out and using the last signal level prior to saturation. The HAS also includes an on-chip temperature sensor, enabling more accurate and efficient measurement and control of the die temperature. Other features of the STAR1000 are also retained such as the ability to accept up to 4 external analogue signals for analogue to digital conversion.

The design of the HAS is documented in final report ‘APS_FF_SC_05_023’ of contract 17235/03/NL/FM. The ICD reference is APS2-CY-FOS-06-004 (version 3.4 at the time of this final report). Both documents are available on request.
Figure 2. Non destructive readout operation

The lessons learnt from the STAR1000 evaluation campaign were implemented in both the assembly configuration and the test methods for the HAS. These lessons have resulted in the selection and testing of a new glass lid epoxy to increase the acceptable upper temperature limits, especially for thermal testing (burn in, step stress testing and thermal cycling), the soldering and de-golding steps. Assembly process changes have also been implemented in order to reduce the moisture level inside, which is a problem for all sensors with a glued glass lid (semi hermetic sealing).

Figure 3. HAS sensor block diagram (Simplified)
Table 1. Overview of HAS sensor specifications with comparison to STAR-1000

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification HAS sensor</th>
<th>Specification STAR-1000 Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel Structure</td>
<td>3-transistor active pixel</td>
<td>3-transistor active pixel</td>
</tr>
<tr>
<td></td>
<td>Radiation-tolerant design</td>
<td>Radiation-tolerant design</td>
</tr>
<tr>
<td>Technology</td>
<td>0.35 µm CMOS</td>
<td>0.5 µm CMOS</td>
</tr>
<tr>
<td>Sensitive area format</td>
<td>1024 x 1024 pixels</td>
<td>1024 x 1024 pixels</td>
</tr>
<tr>
<td>Pixel size</td>
<td>18 x 18 µm</td>
<td>15 x 15 µm</td>
</tr>
<tr>
<td>Pixel output rate</td>
<td>5 MHz (nominal)</td>
<td>5 MHz (nominal)</td>
</tr>
<tr>
<td></td>
<td>Speed can be exchanged for power consumption</td>
<td>Speed can be exchanged for power consumption</td>
</tr>
<tr>
<td>Windowing</td>
<td>X- and Y- addressing random programmable</td>
<td>X- and Y- addressing random programmable</td>
</tr>
<tr>
<td>Electronic Shutter</td>
<td>Electronic rolling shutter. Integration time is variable in time steps equal to the row readout time. Possibility to have non destructive readout (NDR)</td>
<td>Electronic rolling shutter. Integration time is variable in time steps equal to the row readout time.</td>
</tr>
<tr>
<td>Output range</td>
<td>1.3V</td>
<td>1.1V</td>
</tr>
<tr>
<td>Linear range</td>
<td>82,000 electrons (linearity up to ± 5%)</td>
<td>70,000 electrons (linearity up to ± 5%)</td>
</tr>
<tr>
<td>QE x FF (average for the wavelength range of 400 to 720 nm)</td>
<td>40%</td>
<td>22%</td>
</tr>
<tr>
<td>Temporal noise</td>
<td>50 electrons</td>
<td>60 electrons</td>
</tr>
<tr>
<td>FPN</td>
<td>55 electrons &lt; 15 with NDR</td>
<td>365 electrons</td>
</tr>
<tr>
<td>Average dark signal</td>
<td>190 electrons/s at 25 ºC die temperature</td>
<td>785 electrons/s at 25 ºC die temperature</td>
</tr>
<tr>
<td>DSNU</td>
<td>275 electrons/s at 25 ºC die temperature</td>
<td>960 electrons/s at 25 ºC die temperature</td>
</tr>
<tr>
<td>PRNU</td>
<td>0.3%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Total dose radiation tolerance</td>
<td>&gt; 100 KRad (Si) Average DS rise 166 e/s/KRad (Si) at 25 ºC</td>
<td>&gt; 100 KRad (Si) Average DS rise 252 e/s/KRad (Si) at 25 ºC</td>
</tr>
<tr>
<td></td>
<td>Average DSNU rise 20 e/s/KRad (Si) at 25 ºC</td>
<td>Average DSNU rise 50 e/s/KRad (Si) at 25 ºC</td>
</tr>
<tr>
<td>Pixel to Pixel cross talk</td>
<td>10%</td>
<td>17.5%</td>
</tr>
<tr>
<td>Power consumption</td>
<td>115 mW (3.3V power supply)</td>
<td>290 mW (5V power supply)</td>
</tr>
</tbody>
</table>
2 Project management

2.1 Structure

The project consists of 2 main and distinctly different tasks:

- HAS design update and evaluation
- Stand alone ADC development

This final report covers only the HAS evaluation campaign. The development of the stand-alone ADC will be covered by a separate final report.

The key objective this work was to perform a complete evaluation of the existing HAS image sensor and to file an application for entry in the European Preferred Parts List (EPPL). The work was approached in two phases: Firstly, the initial phase of the contract comprised the feedback from industry on possible improvements and the update the sensor design based on this. The second (main) phase of the project comprised the thorough evaluation testing of both image sensors according to established ESA standards (ECC 2269000).

2.2 Schedule

The Request for Quotation was issued in May 2005. Cypress delivered the proposal on July 28, 2005. In order to avoid too much delay in starting the activities during the contract negotiations, a ‘preliminary authorization to proceed’ was issued on January 26, 2006 and the project was formally kicked off March 1st, 2006.

With an initial expected duration of 18 months, the project was originally scheduled to end October 31, 2007 at the HAS TRB. It actually ended in September 2009 with nearly a 2 year delay. The reasons for this delay are discussed later in this section.

The following tables give an overview of the scheduling of the main events:

<table>
<thead>
<tr>
<th>Event</th>
<th>Original date</th>
<th>Actual date</th>
</tr>
</thead>
<tbody>
<tr>
<td>KO</td>
<td>Mar 1, 2006</td>
<td>Mar 1, 2006</td>
</tr>
<tr>
<td>CDR</td>
<td>Aug 31, 2006</td>
<td>June 8, 2006</td>
</tr>
<tr>
<td>TRB</td>
<td>July 31, 2007</td>
<td>April 27, 2007 (pre-TRB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March 12, 2008 (delta-TRB)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>September 2008 (closing)</td>
</tr>
</tbody>
</table>

Due to the decision, after consultation with industry, to do only a minor design update, and not change the on-board ADC, we were able to advance on the planning in the beginning of the project (CDR and TRR). However during evaluation we faced a big delays for several different tests and also to investigate and close issues brought up by unexpected test results. This resulted in a substantial amount of additional investigations and re-testing.

The main reasons for the delay in the HAS evaluation can therefore be summarized as:

- Optimistic planning
• Time needed to test at life-test intermediate points was underestimated and did not include travel time.
• Parallel activities were foreseen but often resulted in not being possible due to test equipment restrictions.
• No time was foreseen for additional investigations and tests and these tests themselves took a long time.

Additional investigations and tests, which are defined at the pre-TRB and delta-TRB, to close all the issues that were observed during evaluation (see NCRs in par. 4.5). These included test assemblies and specific tests requiring hardware or software updates. Each of these needed to be planned on an ad-hoc basis which often meant fitting around other commitments at the test or assembly house.

In addition to these points, the project was started in the middle of the organizational changes due to the integration of FillFactory into Cypress. The temporary disruption caused by such internal changes also added to the programmatic delay. More recent projects have a program manager assigned who is responsible for management tasks, while technical tasks are performed by a design engineer/test engineer/product engineer. This project still had the technical people being responsible for the project management. As a result of this the technical work got in most cases priority over project management work and planning.

Figure 5 shows the schedule of the project. The Grey bars are the original schedule; the blue bars are the final schedule.
<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>WP1200: ISF cycle</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>WP1300: Design and testing review</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>HAS project Review Meeting</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>WP2000: Additional investigations</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>WP2100: ISF design</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>HAS CDR</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>WP2100: ISF FM manufacturing</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>WP2100: subcontractor audits</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>WP2200: wafer, package and glass production</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>WP2300: HAS FM waf test</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>WP4200: HAS FM assembly</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>WP4300: HAS FM production test</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>HAS FM samples available</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>WP4600: Test preparation 16S</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>WP4700: HAS FM test plan</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>WP4800: HAS FM wafer test equipment</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>WP6000: design evaluation system upgrade</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>WP6000: Hals FM production test system</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>WP7000: HAS FM radiation and reliability test system</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>WP4600: HAS FM evaluation program</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>WP4700: subcontractor inspection</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>WP4800: HAS FM evaluation test preparation</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>test equipment commissioning</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>test procedures</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>TRR HAS FM evaluation</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>WP5000: HAS FM evaluation testing</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Inspection</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Initial Measurements</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Destructive Tests</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Step stress</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Radiation</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Total Dose</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Heavy ion</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Construction Analysis</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Package tests</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Electrical Test</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Life Test</td>
<td></td>
</tr>
<tr>
<td>49</td>
<td>additional investigations</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>WP4600: documentation</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>All tests except life test finished (pre TRR)</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>data for TRR ISF FM evaluation</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>First HAS FM delivery date (fully screened)</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>WP1100: SEU testing and modelling</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>Low-Dose Rate Testing Start 1 yr minimum duration (TBD)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Schedule
2.3 CCN

This section gives an overview of the Contract Change Notices that were raised during the project.

*Table 3. overview of contract change notices*

<table>
<thead>
<tr>
<th>CCN</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCN1</td>
<td>Re-definition of the project due to reduced HAS design changes</td>
</tr>
<tr>
<td>CCN2</td>
<td>Additional low-dose rate test for HAS</td>
</tr>
<tr>
<td>CCN3</td>
<td>Outsource of HAS test equipment manufacturing</td>
</tr>
<tr>
<td>CCN4</td>
<td>Key personnel</td>
</tr>
<tr>
<td>CCN5</td>
<td>Planning and milestone payment plan</td>
</tr>
</tbody>
</table>
3 Phase 1: Industry feedback and design update

During phase 1 the European space industry that tested the HAS prototypes was visited and possible design and/or performance changes were discussed. The following companies were involved in this review and discussion phase:

- ESA
- EADS Sodern
- Galileo Avionica
- Jena Optronik

A complete list of the ideal desires and ‘wishes’ for improvements and changes was assembled. See section 6 for the list. However, industry were rather unanimous in stating that they had found workarounds for all of the known undesirable features of the detector and they had a strong preference to not change the die for fear of introducing other, as yet unknown, side effects.

ESD sensitivity was shown to be an issue on STAR250 and STAR1000 and therefore a preliminary ESD test was executed on the prototype HAS detectors to assess the ESD sensitivity. The result was that a few pins are already failing at 250V, which is worse than the STAR devices. Investigation in the design showed that these pins had the ESD protection structures not connected. It was decided that this was an essential and risk free area to be fixed in the move to a flight device and the design was updated accordingly.

The glass lid deflection under vacuum was raised as a concern, and a test showed a 10um deflection on the original 1.0mm thick lid. This was in line with predictions but would give additional errors to the Star Trackers in orbit. The glass lid thickness was therefore increased to 1.5mm, reducing the deflection to 3 microns which was insufficient to produce additional errors.

STAR250 and STAR1000 clearly showed an issue with the performance of the window epoxy at 125 °C. Therefore a new epoxy was selected that should be better performing at high temperatures. Various early validation tests were performed on this epoxy prior to selecting it for the qualification batch:

- Outgassing test
- Glass lid pull tests

The results of these tests were good and indicated that a switch to this new epoxy should be undertaken with the full testing being performed during the evaluation.

In summary, and due in part to the timing restrictions of the coming missions and the level of unit design already performed by the users, the following was decided:

- No major redesign of the sensor (die or package)
- A minor die re-work to be performed to connect the ESD structures at the pins where they are not.
- Change of the glass lid to increase to 1.5mm thickness
- Use of a new epoxy, ‘SMG3’, for the window attachment.

A CDR was held at Cypress to confirm and approve the proposed changes. The nomenclature of the detector was changed to HAS2 after the implementation of these changes in order to distinguish between the prototype devices and the updated design.
4 Phase 2: detailed evaluation of HAS2

4.1 Introduction

It was chosen to do a complete evaluation conform to ESCC 2269000 and apply for EPPL entry. The full qualification, conform to ESCC 9020, and QPL entry is outside the scope of this project but it stays open as an option. An evaluation program is similar to a qualification in that the same, or even more, tests are performed, but the devices are overstressed in order to detect the different failure modes and hence discover the pass/fail criteria that should be set for the test during a qualification campaign. A qualification campaign is then a formal re-run of the same tests but with lower limits, set pass/fail criteria and – for some tests – being performed on screened as opposed to unscreened devices. As an example, in the evaluation testing mechanical vibration is performed with 50 cycles in stead of 5 cycles for the qualification tests.

In the past the HAS has been subjected only to characterization tests and preliminary radiation testing. These tests gave good confidence for the success of the evaluation campaign but are far from sufficient for a full evaluation.

The evaluation program performed is conforming to ESCC 2269000 and consists of the following key parts:

- Initial measurements
- A control group
- Temperature step stress test
- Radiation tests, including total dose, proton and SEU
- Construction analysis
- Package tests:
  - Thermal cycling and thermal shock
  - Mechanical shock and vibration
  - Moisture resistance
  - Resistance to soldering heat
  - Solderability and lead fatigue
- Electrical tests
  - ESD
  - Electrical characterization vs. power supply voltage
  - Electrical characterization vs. temperature
- Endurance/ Accelerated Life test

An important difference between evaluation and qualification is that evaluation is performed on unscreened devices, while qualification has to be done on screened devices. In order to avoid that the qualification needs to be repeated, some of the tests (radiation test and life test) have been done on devices that received a burn-in – this being the biggest difference between the screened and unscreened parts.

4.2 Evaluation test plan

The evaluation test plan for the HAS2 image sensor was based upon ESA basic specification ESCC 2269000. Figure 6 shows an overview of the entire evaluation plan. In total 111 HAS2 devices were submitted to the tests.

After procurement (P4) of sufficient devices in accordance with the PID, the complete batch was subjected to inspection (P5) resulting in a list of devices that were to be used for the evaluation program. Special attention was paid to maintain a control group of 10 devices of each kind that did not undergo any stress. During all subsequent measurements before and after stress, burn-in or radiation...
these devices were measured in the same measurement session to prove the proper operation of the test infrastructure.

During the initial measurements (P6) all devices were characterized at room temperature and at the extreme operating temperatures: -40 °C and +85 °C. Next two subgroups were formed to perform the destructive tests and the endurance tests. Apart from these groups the control group was selected and 5 devices of each were kept apart as reserve.

The destructive tests (Group 2) consisted of the following parts:

- A step-stress test to determine the temperature at which to conduct the endurance test.
- A radiation test containing total dose, proton and heavy ion irradiation.
- Construction analysis by ESTEC to verify the design of the product.
- Package tests to verify the assembly configuration (combination of package, die and glass lid)
- Electrical tests consisting of ESD tests and parametric tests in function of temperature and supply voltage.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of HAS devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: Control Group</td>
<td>10</td>
</tr>
<tr>
<td>Group 2: Destructive tests</td>
<td>82</td>
</tr>
<tr>
<td>Subgroup 2A: Temperature step stress test</td>
<td>9</td>
</tr>
<tr>
<td>Subgroup 2B: Radiation tests</td>
<td>30</td>
</tr>
<tr>
<td>Subgroup 2Bi: Total dose radiation tests</td>
<td>12</td>
</tr>
<tr>
<td>Subgroup 2Bii: Proton radiation tests</td>
<td>15</td>
</tr>
<tr>
<td>Subgroup 2Biii: Heavy ion radiation tests</td>
<td>3</td>
</tr>
<tr>
<td>Subgroup 2C: Construction analysis</td>
<td>3</td>
</tr>
<tr>
<td>Subgroup 2D: Package tests</td>
<td>33</td>
</tr>
<tr>
<td>Subgroup 2E: Electrical tests</td>
<td>7</td>
</tr>
<tr>
<td>Group 3: Endurance tests</td>
<td>15</td>
</tr>
<tr>
<td>Subgroup 3B Accelerated electrical endurance test</td>
<td>15</td>
</tr>
<tr>
<td>Group 4: Spare</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>111</strong></td>
</tr>
</tbody>
</table>
Figure 6. Evaluation program overview
A dedicated test set-up was developed to perform all initial, intermediate and final electrical and electro-optical tests. This test system is capable of testing all parameters that are listed in Table 2 of the detailed spec.

Figure 7. HAS dedicated tester setup
4.3 Evaluation test results

4.3.1 Initial inspections and tests (P5)
All initial inspections and tests are performed on 100% of the evaluation assembly batch of detectors.

4.3.1.1 Initial visual inspection
All devices are being inspected in a class 100 clean environment. A microscope is used to do the detailed inspection. The parameters checked for during inspection are listed below:

- Pins
- Glass lid
  - Placement
  - Cleanliness
  - Scratches- other defects
- Glass lid epoxy
  - Width
  - Bubbles, defects
- Marking
- Wire bonds
- Die attachment
- Die cleanliness (particles, scratches, ...)
- Die
  - Metallization
  - Passivation
  - Chipping

The parameters above are being inspected according the ESCC basic specification 2049000: “Internal visual inspection of integrated circuits”. Particles and artifacts (Table 5) were found during this 100% visual inspection:

<table>
<thead>
<tr>
<th>Bin</th>
<th>Number of devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bended pins</td>
<td>21</td>
</tr>
<tr>
<td>Die attachment glue residue (on bond wire or silicon)</td>
<td>43</td>
</tr>
<tr>
<td>Bottom glass lid contamination</td>
<td>69</td>
</tr>
<tr>
<td>Lot of particles on silicon</td>
<td>36</td>
</tr>
<tr>
<td>Big particles, scratches &amp; digs</td>
<td>19</td>
</tr>
<tr>
<td>Top glass lid contamination</td>
<td>1</td>
</tr>
<tr>
<td>Small number of particles</td>
<td>69</td>
</tr>
<tr>
<td>Zero artefacts</td>
<td>1</td>
</tr>
<tr>
<td>Zero particles on silicon</td>
<td>6</td>
</tr>
</tbody>
</table>

Due to the high number of particles and artifacts discovered at this early stage, NCR 1 was raised. This problem had no impact on the actual evaluation program, as these issues do not affect the testing, but has a non-negligible impact on the potential FM yield and therefore needed to be resolved. Under NCR 1 the causes and solutions for these issues were investigated and demonstrated. The conclusions of NCR1 were:
1. Witnessing is important for FM assembly jobs. Therefore all STAR and HAS FM assembly jobs will be witnessed by Cypress and the PID will contain this requirement.
2. N2 glove box needs a particle filter on the N2 intake
3. Gloves of the glove box are a source of contamination. This is caused by the degradation of the gloves.
4. Visual inspection at MPD is not up to the same level as at Cypress. In the short term this will not change.

Bullets 1 to 3 were implemented and further assembly lots showed that the problems were solved and the number of particles and artifacts had fallen significantly.

4.3.1.2 Electrical test
124 HAS2 devices were tested with a test system that was specially designed for this project. The next table lists the spread of the results of some of the key parameters. These values are only initial test values and are therefore not equivalent to the specifications that are listed in the HAS2 detailed specification. See paragraph 4.3.2 for the complete table 2 test results. As can be seen, with the exception of the dark current, all values show very little variation from device to device.

Table 6. Results spread of most valuable parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Std_Dev</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby current [mA]</td>
<td>18.26</td>
<td>0.29</td>
<td>17.6</td>
<td>19.1</td>
<td>18.3</td>
</tr>
<tr>
<td>Total Operational Current [mA]</td>
<td>37.15</td>
<td>0.66</td>
<td>35.1</td>
<td>38.8</td>
<td>37.1</td>
</tr>
<tr>
<td>Output swing [V]</td>
<td>1.43</td>
<td>0.30</td>
<td>1.43</td>
<td>1.57</td>
<td>1.49</td>
</tr>
<tr>
<td>Global FPN [e/s] SR</td>
<td>72.35</td>
<td>2.75</td>
<td>67.66</td>
<td>81.84</td>
<td>71.76</td>
</tr>
<tr>
<td>Global FPN [e/s] HR</td>
<td>110.18</td>
<td>3.55</td>
<td>103.84</td>
<td>120.43</td>
<td>109.96</td>
</tr>
<tr>
<td>Global FPN [e/s] HTS</td>
<td>89.46</td>
<td>5.46</td>
<td>82.59</td>
<td>129.74</td>
<td>88.24</td>
</tr>
<tr>
<td>Dark current [e/s] 25 °C BOL</td>
<td>333.44</td>
<td>50.34</td>
<td>196.94</td>
<td>470.96</td>
<td>327.58</td>
</tr>
<tr>
<td>Global PRNU [%]</td>
<td>1.43</td>
<td>0.67</td>
<td>0.75</td>
<td>3.41</td>
<td>1.174</td>
</tr>
</tbody>
</table>

4.3.1.3 Dimensions check
Outer dimensions as well as die positioning have been measured and specs have been defined. The following has been measured:

- X and Y dimensions
- Die positioning in X and Y
- Glass planarity/total thickness
- Die placement planarity
- Silicon to glass planarity
Figure 1. Package drawing top view

Figure 2. Package drawing side view
Figure 3. HAS2 assembled device side view

Figure 4. Die placement dimensions
4.3.1.3.1 X and Y dimensions
The X and Y dimensions are the outer dimensions of the ceramic package (including the pins). 10 devices have been measured:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Average</th>
<th>Sigma</th>
<th>Min</th>
<th>Max</th>
<th>Min spec</th>
<th>Max spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>30.18</td>
<td>0.019</td>
<td>30.15</td>
<td>30.21</td>
<td>30.10</td>
<td>30.36</td>
</tr>
<tr>
<td>Y</td>
<td>30.18</td>
<td>0.020</td>
<td>30.15</td>
<td>30.21</td>
<td>30.10</td>
<td>30.36</td>
</tr>
</tbody>
</table>

All values are within specification.

4.3.1.3.2 X-Y positioning/rotation
X-position, Y-position and rotation are measured using a De Meet 3D measurement microscope. As the die is placed in the middle of the cavity, all values are ideally 0.

<table>
<thead>
<tr>
<th>Dimension (um)</th>
<th>Average</th>
<th>Sigma</th>
<th>Min</th>
<th>Max</th>
<th>Min spec</th>
<th>Max spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-shift</td>
<td>72</td>
<td>26</td>
<td>33</td>
<td>142</td>
<td>-100</td>
<td>+100</td>
</tr>
<tr>
<td>Y-shift</td>
<td>13</td>
<td>30</td>
<td>-60</td>
<td>+45</td>
<td>-100</td>
<td>+100</td>
</tr>
<tr>
<td>Rotation</td>
<td>14</td>
<td>19</td>
<td>-17</td>
<td>67</td>
<td>-100</td>
<td>+100</td>
</tr>
</tbody>
</table>

Except for a few ‘outliers’, all devices are within spec. However it is the intention to narrow the specification to maximum 50um deviation for the spec. This will be done by fine-tuning of the die bonding equipment during the next assembly batches. It is verified during FM screening as die position measurements are part of the screening flow.

4.3.1.3.3 Glass planarity/total thickness
Glass planarity and total thickness are measured using a De Meet 3D measurement microscope. This is a measurement on 20 devices of the distance between ceramic backside and glass lid top in the 4 corners.

<table>
<thead>
<tr>
<th>Measurement (mm)</th>
<th>Average</th>
<th>Max-Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td>3.4325</td>
<td>0.19</td>
</tr>
<tr>
<td>min</td>
<td>3.3375</td>
<td>0.03</td>
</tr>
<tr>
<td>average</td>
<td>3.3923</td>
<td>0.0935</td>
</tr>
<tr>
<td>stdev</td>
<td>0.0283</td>
<td>0.0456</td>
</tr>
<tr>
<td>av+3s</td>
<td>3.4771</td>
<td>0.2302</td>
</tr>
<tr>
<td>av-3s</td>
<td>3.3074</td>
<td>-0.0432</td>
</tr>
</tbody>
</table>

The average thickness of the assembled device measured 3.39mm with a standard deviation of 0.028mm. The planarity is measured < 0.09mm with a standard deviation of 0.045mm. These results show that the total thickness and glass planarity are stable values.
4.3.1.3.4 Die placement planarity

Die placement planarity is measured using a De Meet 3D measurement microscope. It is a measurement on 5 devices of the cavity bottom versus the die top surface in the 4 corners.

<table>
<thead>
<tr>
<th>Measurement (mm)</th>
<th>Average</th>
<th>Max-Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td>0.7853</td>
<td>0.050</td>
</tr>
<tr>
<td>min</td>
<td>0.7721</td>
<td>0.036</td>
</tr>
<tr>
<td>average</td>
<td>0.7768</td>
<td>0.0447</td>
</tr>
<tr>
<td>stdev</td>
<td>0.0053</td>
<td>0.0055</td>
</tr>
<tr>
<td>av+3s</td>
<td>0.7927</td>
<td>0.0612</td>
</tr>
<tr>
<td>av-3s</td>
<td>0.7609</td>
<td>0.0283</td>
</tr>
</tbody>
</table>

The average difference between the die cavity and the die measures 0.7768 mm with a standard deviation of 0.053mm. The planarity measures < 0.045mm with a standard deviation of 0.0055mm.

4.3.1.3.5 Silicon to glass lid planarity

This is a measurement of the distance between silicon top surface and the top of the glass lid in the 4 corners.

<table>
<thead>
<tr>
<th>Measurement (mm)</th>
<th>Average</th>
<th>Max-Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>max</td>
<td>1.899</td>
<td>0.223</td>
</tr>
<tr>
<td>min</td>
<td>1.834</td>
<td>0.037</td>
</tr>
<tr>
<td>average</td>
<td>1.861</td>
<td>0.1094</td>
</tr>
<tr>
<td>stdev</td>
<td>0.025</td>
<td>0.0865</td>
</tr>
<tr>
<td>av+3s</td>
<td>1.936</td>
<td>0.368</td>
</tr>
<tr>
<td>av-3s</td>
<td>1.785</td>
<td>-0.150</td>
</tr>
</tbody>
</table>

The average distance between the silicon and the top of the glass lid measures 1.861 mm with a standard deviation of 0.025mm. The planarity is measured < 0.1094mm with a standard deviation of 0.00865mm.

4.3.1.3.6 Dimensions Conclusions

All dimensions measured are in line with the specifications. (See detailed specification). Before and after the screening of the FM devices all dimensions are verified.

4.3.1.4 Weight

The devices have been weighed, all device weighed between 7.8 and 7.9 grams.

4.3.1.5 PIND test

The purpose of this test is to detect small particles inside the cavity that were overlooked or were not visible during visual inspection.

For FM devices this test will be used as a Mobile Particle test. By doing particle mapping before and after the PIND test, it will be clear if a particle is mobile or not.
All devices are tested in accordance with ESCC Generic Specification 9020, paragraph 9.7. All devices successfully passed the PIND test. No signal was observed during the test.

### 4.3.1.6 Radiographic inspection

The purpose of this test is to detect anomalies that can not be seen by visual inspection: die bond epoxy coverage, metallization inside the package etc.

All devices (100%) were inspected in accordance with ESCC basic specification 20900. The acceptance criteria for voids are:

- Minimum 50% die bond epoxy coverage
- No voids traversing the die

Radiographic inspection showed no anomalies for the die attachment onto the ceramic. In total 3 pictures were taken per device (1 top view + 2 side views). The radiographic inspection is part of the screening of FM devices.

![Figure 8. Top view X-ray inspection](image)

### 4.3.1.7 Hermeticity test

The purpose of the test is to detect leakage of the package and the seal between the package and the glass lid.

Test method:
- Fine Leak test: MIL-STD-883, Test Method 1014, Condition A
- Gross Leak test: MIL-STD-883, Test Method 1014, Condition C

The required leak rate for fine leak is $5 \times 10^{-7}$ atms. cm$^3$/s

All devices passed the fine and gross leak. Fine leak measurements were in the range: $2.07 \times 10^{-9}$ atms. cm$^3$/s – $2.57 \times 10^{-9}$ atms. cm$^3$/s
4.3.1.8 Marking and serialization
The purpose of the test is to verify if all devices are properly marked and have a unique identification. All devices applied to the test campaign have received a unique ID number. The HAS2 marking consists of:

HAS2-FM
Serial number (6 digits)
Assembly date code (YYMMDD)

An example of the marking:
HAS2-FM
000135
080526

4.3.1.9 Pre burn in test on total dose radiation test devices
The 15 devices that were subjected to total dose irradiation first had a 240h pre burn in at 125 °C. During burn in all devices were operated constantly. A current monitoring was performed on every device to check for any anomaly during the burn in session. No anomalies or parameter drifts were detected during burn in. All devices were tested for fine and gross leak after the burn in session. All devices passed the test.

4.3.1.10 Pre burn in on life test devices
The 15 devices that were selected for the life test first had a 240h pre burn in at 125 °C. During burn in all devices were constantly under operational conditions. A current monitoring was performed on every device to check for any anomaly during the burn in session.

All devices were tested for fine and gross leak after the burn in session. One device, nr. 190, failed for both fine and gross leak testing but is not considered as an issue for the purpose of the intended test. After this burn-in session a problem was discovered in the results of the current monitoring. All devices had a current that was too low compared to the expected value. The reason for the bad current was due to a bad contact between the driver PCB and the burn in PCB. Because of this problem NCR 11 was raised and had the following conclusion:

• When installing equipment at subcontractors, always include verification steps for the subcontractor to identify the correct operation of the equipment. This will be added to general ‘best practice’ list for space programs, and also non-space programs.

This problem had no impact on the purpose of the test. All the devices retrieved an extra burn in step of 240h with the correct operational requirements.

4.3.1.11 Materials and finishes
These tests are designed to assess:

• The outgassing properties of the die bond epoxy and glass lid epoxy
• The determination of the glass lid deflection
• Glass lid strength by performing a glass lid pull and torque test
• Anti-Reflective Coating testing

The tests are each summarized in the following sections.

4.3.1.11.1 Epoxy outgassing
The die bond and glass lid epoxies have been tested for outgassing. For the die bond epoxy, this was already tested in the framework of the STAR250/STAR1000 evaluation. The results are repeated. The glass lid epoxy is a new epoxy, and was therefore tested for outgassing in accordance with specification ECSS-Q-70-02
The pass/fail criteria are:

- Total Mass Loss (TML): < 1%
- CVCM: < 0.1%

The following measurement results were obtained:

<table>
<thead>
<tr>
<th>Epoxy</th>
<th>TML [%]</th>
<th>CVCM [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die bond epoxy</td>
<td>1.101 ± 0.06</td>
<td>0.004 ± 0.004</td>
</tr>
<tr>
<td>Glass lid epoxy</td>
<td>0.083 ± 0.004</td>
<td>0.000 ± 0.001</td>
</tr>
</tbody>
</table>

The die bond epoxy is the same as the one used on STAR250/STAR1000. The glass lid epoxy used on STAR250/STAR1000 showed a TML of 0.842 and CVCM of 0.007.

Conclusion:

- The TML of the die bond epoxy is marginally out of spec. However this epoxy was approved to be used, as additional bake-out (125°C/24h) is performed before glass lid attach.
- A 24h pre-bake at 125 °C is done before glass lid attach to outgas the die bond epoxy additionally in that way that a better TML is achieved. (not tested)
- This die bond epoxy was also used for the STAR250 and STAR1000 and is therefore considered as suitable to us for the HAS as well. RGA showed no aggressive chemicals.
- The outgassing of the glass lid epoxy is well within specification, and is a significant improvement over the glass lid epoxy used on STAR250 and STAR1000.

4.3.11.2 Glass lid deflection test

The glass lid deflection test is being performed at the ESTEC laboratories. The deflection is being measured by pasting the APS onto an alumina surface with the measurement sensor being placed in the middle of the sensor. By sucking the air out of the chamber the deflection is being obtained. The figure below shows the measurement setup.

![Glass lid deflection measurement setup](image)

A measurement run consists of a repressurization and derepressurization of the chamber. During this run the deflection is being measured. In total 3 runs were applied. The temperature of the test setup was being monitored during the entire measurement and was constant 23 °C.
The deflection measured was 2.8\(\mu m \pm 0.1\mu m\). The predicted deflection from analysis was 3\(\mu m\) so the test results and the analysis are in very good agreement.

4.3.1.11.3 Glass lid pull test
The glass lid pull test is being performed at the assembly house. A stud is being glued onto the glass lid and onto the ceramic package. A force is being applied on both studs in opposite direction. The tests are performed on three samples. The results for the pull test are listed below.

<table>
<thead>
<tr>
<th>Glass lid</th>
<th>Force (N)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass lid 1</td>
<td>381N</td>
<td>(mechanical stud detached from glass lid)</td>
</tr>
<tr>
<td>Glass lid 2</td>
<td>501N</td>
<td>(mechanical stud detached from glass lid)</td>
</tr>
<tr>
<td>Glass lid 3</td>
<td>317N</td>
<td>(mechanical stud detached from glass lid)</td>
</tr>
</tbody>
</table>

For the new glass lid (see par. 4.4), the results are between 482 Nm and 554 Nm, i.e. the new configuration, now part of the standard product, shows a higher average and a lower dispersion in the results.

4.3.1.11.4 Glass lid torque test
The glass lid torque test is being performed at the ESTEC laboratories and is performed in accordance with MIL Std 883 method 2024. In total two devices were submitted to the test which were derived from the evaluation lot.

The torque was applied to two sides of the window and against two perpendicular sides of the ceramic body. In order to achieve contact along the whole side of the body the “J” leads were carefully removed from two complete and opposite sides of both parts tested.

![Figure 10. Lid torque test setup](image)

The maximum torque recorded for the parts was 11.2 and 16.9 Nm. In both cases the glass lid detached from the package showing that the failure mechanism is the epoxy bonding.

The seal area was calculated as 9 to 10 square mm for which the Mil Std gives a recommended minimum shear force of 12.8 Newton meters. However, these limits are applicable to glass frit sealed packages and are not intended for use with epoxy/glass seals. They are only included here for reference purposes only. Considering that this is an epoxy seal, the results for these parts are considered satisfactory.
For the new glass lid configuration (see par. 4.4), the torque results are between 13.5 and 20 Nm and the failure mechanism is a failure in the ceramic or glass rather than a failure in the epoxy bonding.

4.3.1.11.5 Anti-reflective coating test
The objective of the activity is to perform the testing of the ARC coating of the HAS2 glass lid to assess the quality and the operating limits of the pieces, thereby allowing also sufficient documented information to enable a successful application for the devices to be placed on the EPPL.

The quality of the anti reflective coating is being tested in accordance with MIL standard MIL-C-675C.

The testing of the anti reflective coating on the HAS2 glass lid consisted of 6 different tests. All these tests are compliant to the MIL Standard MIL-C-675C.
1. Severe Abrasion Test
2. Immersion Test
3. Climate Test
4. Salt Fog Test
5. Moderate Abrasion Test
6. Adhesion Test

Every time a test was finished the glass lid has been inspected for anomalies.

Conclusion:
The coated components supplied for test are durable and exceed the MIL-C-675C. No degradation or de-lamination of the coating was observed

An optical change was measured after immersion, climate and salt fog tests but are not critical for the intended application and will therefore be considered as “use as is”. The Optical changes were due to stains and residues which were not completely removed from the glass lid prior to the measurement. This was verified with a re-measurement of the parts after detailed cleaning.

4.3.2 Initial measurements (P6)
The purpose of this test is to do a full electrical and electro-optical test (conform to Table 2 and Table 3 of the detailed specification) on all devices selected for the evaluation campaign. These tests are repeated after each of the stresses of the evaluation program. The main tests are:

- Power dissipation
- Temporal Noise
- Fixed pattern noise
- Dark Current
- Dark signal non uniformity
- Pixel response non uniformity

The results were used to set the specs and testing limits for the FM devices. The results were as expected, with the exception of the ADC INL and DNL measurement. This measurement is considered to be incorrect, and special hardware to do a correct INL and DNL measurement is in development.

It was a failure in the development of the HAS tester and we have decided to not change the tester as it would have a tremendous impact on the overall qualification program. The measurement was affected by system noise. With the special hardware we have limited the system noise and a direct path was created from DAC to ADC. This was not the case for the tester.
4.3.3 Evaluation

4.3.3.1 Control group (Group 1)

The purpose of the control group is to have a set of reference samples that get no tests or stresses. These devices, or a subset, will be tested each time together with the stressed devices. Variations in the characteristics of the control group samples show the test system’s issues over time.

4.3.3.2 Destructive tests (Group 2)

The purpose of this group is to overstress the devices by electrical and environmental stress and by ionizing radiation in order to detect the failure mode. The following destructive tests are performed:

- Temperature step stress test: test where the temperature is raised in steps until the devices fail (biased test).
- Radiation test: test where the devices are radiated in order to detect radiation sensitivity. This includes total dose test, proton test and heavy ion test.
- Constructional analysis: to detect constructional or design defects which may affect reliability.
- Package tests: thermal and mechanical tests to detect anomalies in the assembly configuration (package, glass lid, assembly process)
- Electrical tests: ESD sensitivity and characterization vs. power supply voltage and temperature

4.3.3.2.1 Temperature step stress test (Subgroup 2A)

This subgroup contains a thermal resistance measurement and a temperature step stress test. Both tests are done with different devices due to the destructive nature of the tests. Before step stress can be performed, the device thermal resistance needs to be measured. Both tests were done in accordance with the relevant MIL specs.

- Thermal resistance measurement: MIL-STD-883 method 1012 RD05.

*Important note: A power step stress test is not relevant for APS detectors and is therefore not performed.*

Determination of thermal resistance / conductivity

Measurements of junction-to-case and junction-to-ambient thermal resistance were carried out in accordance with MIL STD 883, Method 1012.1. All measurements of junction temperature were performed in accordance with the ‘switching method’ stipulated by MIL STD 883, Method 1012.1. During the measurements an issue was encountered which lead to an incomplete dataset. The initial junction-to-ambient thermal resistance measurement, the current required for device heating exceeded the tolerances of the device, essentially destroying the device; as such further measurements on the device could not take place. This again occurred during junction-to-case testing with device B. The tables below are listing the outcome of the thermal resistance measurement.

<table>
<thead>
<tr>
<th>Table 13. Junction-to-case thermal resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Thermal resistance</td>
</tr>
</tbody>
</table>

The thermal resistance measurements are in line with the expectation: on previous measurements (STAR250 & STAR1000) we had about the same values (junction-to-case). For STAR250 a thermal resistance of 5.11 °K/W and for STAR 1000 3.63 °K/W was measured.

**Temperature step stress test.**

The purpose of this test is to determine the thermal conditions for the accelerated endurance test. The thermal resistance measurement defines what temperature has to be used in order to have a known
temperature for the die. The temperature step stress test defines the temperature where the device fails, which is used to define the temperature of the endurance test.

The step stress test was executed for 168h at each of the following temperatures: 125°C, 150°C and 170°C. Between each step stress test the sensor was cooled down to room temperature and its electrical behaviour (table 2 in ICD) and hermeticity tested (fine and gross leak testing).

During this test the devices where in continuously operation mode and the driving currents for the 5 devices were constantly monitored. The measured currents during each 7 days stress showed no abnormalities or drifts.

After the third step stress test the devices were sending back to Cypress for a complete Table 2 electrical test. The outcome of this test was successful. The results were compared with the initial tested values and no abnormalities or parameter drifts were detected. Fine and gross leak tests were all successful.

**Conclusion:**
The step stress tests have proven that the right choice is made for the new glass lid attachment glue. In comparison with the glass lid attachment glue used for the STAR250 and STAR1000, which was only resistant to temperatures up to 120 degrees, this glue has proven its heat resistance till 170 degrees.

To be consistent with the STAR250 and STAR1000 an operating temperature of 125 degrees Celsius is chosen for the accelerated endurance test although this could have been extended up to 170 degrees. This is an important lesson for the future as a higher temperature during the accelerated life test results in a higher demonstrated lifetime in orbit. For an operating temp in orbit of 10 deg C, the life test at 125 deg C demonstrates an equivalent 8 years life. If conducted at 170 deg C, this would increase to >19 years.

### 4.3.3.2.2 Radiation tests
The purpose of this test is to determine the tolerance against ionising radiation, SEU and latch-up susceptibility. The devices are evaluated under total dose, proton irradiation and the Single Event Effects (SEE). All devices were continuously monitored. One device out of these was monitored in full operation.

#### 4.3.3.2.2.1 Subgroup 2Bi – Total dose radiation test

#### 4.3.3.2.2.1.1 Introduction
The irradiations were performed at the ESTEC Cobalt 60 irradiation facility in Noordwijk (NL) in January/February 2007. The subsequent annealing at room temperature and at elevated temperature was done at Cypress from February till May 2007.

The hardware, firmware and software to bias and drive the components during irradiation were developed by Cypress.
4.3.3.2.2.1.2 Radiation levels and dose rates

The list below contains an overview of the irradiation levels and dose rates. The irradiation sessions were given an identification tag to facilitate later identification and processing control of measurement data.
Table 14. Radiation table

<table>
<thead>
<tr>
<th>Session</th>
<th>1</th>
<th>2</th>
<th>3.1</th>
<th>3.2</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose rate (Rad/min)</td>
<td>12.06</td>
<td>13.14</td>
<td>13.23</td>
<td>16.2</td>
<td>16.2</td>
<td>50.4</td>
</tr>
<tr>
<td>Achieved dose (Krad)</td>
<td>4.1</td>
<td>8.7</td>
<td>3.6</td>
<td>3.8</td>
<td>21.4</td>
<td>349</td>
</tr>
<tr>
<td>Accumulated dose (Krad)</td>
<td>4.1</td>
<td>12.8</td>
<td>16.4</td>
<td>20.2</td>
<td>41.6</td>
<td>349</td>
</tr>
</tbody>
</table>

4.3.3.2.2.1.3 Initial measurements

Pre burn in
All devices selected for the irradiation campaign had a pre burn in of 240h at 125 °C. During pre burn in all devices were clocked and biased. Current monitoring was done on all devices. The results of this test were written into an excel file. The current monitoring showed no anomalies or parameter drifts.

Detailed optical characterization
3 devices were tested conform table 8 of the ICD. Measurements were done before pre burn in, after pre burn in and after irradiation. In that way we have a clear view on the changes that might have occurred to the sensor during stresses.

HCRT test
All 15 devices were tested conform Table 2 of the ICD at stabilized hot (+85 °C), cold (-40 °C) and room temperature (+25 °C).
Device 163 gave an over current in standby condition at high temperature. This problem was seen in previous measurements. Although no design justification could be given for this behaviour, it has been demonstrated that this type of failure is captured during screening and therefore does not affect FM devices (see NCR5).

4.3.3.2.2.1.4 Measurements performed during irradiation

Current monitoring
During each irradiation session the current of each sensor was monitored. From one device (socket 9) it was possible to download images. The current monitoring during sessions 1 to 5 showed no anomalies or parameter drifts of the devices.

Electrical test
After each irradiation session the sensors were tested conform Table 2 of the detailed specification. To be sure the test system was 100% in good shape, 3 witness samples (ID’s 205, 192 and 187) were measured every session.

Figure 12 shows the test setup during the irradiation campaign.

4.3.3.2.2.1.5 Test results
The following paragraph discusses the most important measured values during irradiation and during annealing. For each measured value the average value is plotted to indicate the trend in function of irradiation dose or anneal time. In each graph two curves are plotted: one for the irradiated samples and one for the witness samples.
In total two annealing steps were performed.
- 168h High temperature annealing at 125 °C biased and unbiased.
- 3 Months room temperature annealing unbiased for all devices

4.3.3.2.2.1.5.1 Power supply current
At room temperature none of the power supply currents increased under irradiation. At the end of the irradiation campaign all device were tested at stabilized hot (+85 °C), cold (-40 °C) and room temperature (+25 °C). Only at hot temperature there was a significant increase of the power supply current in standby mode, this difference between the hot and RT behaviour was not expected and
therefore NCR 9 was raised. The problem description, investigations and solutions are described in this NCR.

NCR 9 conclusion:
The root cause of the increased standby current is thought to be due to charge leakage in either the N-MOS transistors or in the N-Well structures. This cannot be improved as it appears to be process related. As this effect is only present in stand-by mode in hot condition at EOL, and the increased power supply current is still lower than the operational power supply current, this is considered not to be a serious issue.

4.3.3.2.1.5.2 Fixed Pattern Noise
All FPN figures described below are measured in Destructive Readout.

**Soft reset mode**

![Local and Global FPN in Soft Reset Mode](image1)

*Figure 13. Local an Global FPN in Soft Reset Mode vs TID irradiation*

The graph above displays the local and global FPN as a function of radiation and annealing. As can been seen on the graph, a large increment is visible between 20 and 40 Krad. The sequence of grabbing images is the root cause of this problem. Before taking image in soft reset, images are been taken in hard reset. Hard reset sets the reset voltage of the pixel on 4.2V. If an image is taken in soft reset, 3.3V, right after a hard reset, the chance is there that the pixel is not yet discharged. With increasing irradiation the dark current of the pixel is increasing as well. Between 0 and 20Krad the influence of the dark current is smaller then the influence of the hard reset. After 20K the dark current probably gets the overhand. And this effect is causing the high FPN value measured at 40Krad.

**Hard reset mode**

The graph displays the local and global FPN as a function of radiation and annealing. As can been seen on the graph, a decrement is visible with increasing radiation. According to the graph the FPN is better after radiation but actually this is not the case. Analysis of the images showed that this effect is mainly driven by the end of the image. Probably a crosstalk between PGA, ADC and column bus offset causing this phenomena. When looking to the consecutive FPN images it seems that cross talk gets...
better with increasing irradiation. Probably this is due to the fact that the temporal noise (which is still in the FPN image) is increasing too with the irradiation and that from that point forwards the temporal noise is getting the overhand.

![Local and Global FPN in Hard Reset Mode](image1)

*Figure 14. Local and Global FPN in Hard Reset Mode vs TID irradiation*

**Hard to soft reset**

![Local and Global FPN in Hard to Soft Reset Mode](image2)

*Figure 15. Local an Global FPN in Hard to Soft Reset Mode vs TID irradiation*
FPN histogram plot versus radiation

![FPN Histogram plot versus TID radiation](image)

**Figure 16. FPN Histogram plot versus TID radiation**

4.3.3.2.1.5.3  Dark Current

![Dark Signal versus Irradiation](image)

**Figure 17. Dark Signal versus TID irradiation**
The graph above displays the dark signal versus irradiation duration for every of the single radiated devices. The following observations can be made directly:

- Average dark signal rises during irradiation.
- Dark signal gets better after annealing the device under bias conditions.
- Dark signal of unbiased sensors get worse after annealing.
- Until 20Krad the spread between the different samples is small. Between 20Krad and 40Krad the spread increases.

The dark current rises under irradiation. As an approximation a linear fit was made through the measured data.

Average dark signal rise under radiation: **165,78 e-/s per Krad @ 25 °C**

This value is in line with the expected value outlined in the detailed specification.

4.3.3.2.1.5.4 Dark Current Non Uniformity

The graph above displays the dark signal non uniformity versus irradiation duration. The following observations can be made directly:

- Average DSNU rise during irradiation
- In comparison with the dark signal DSNU doesn’t get significantly better after annealing.
- In comparison with the dark signal there is no difference in DSNU between biased and unbiased devices

The dark signal non uniformity rises under irradiation. As an approximation a linear fit was made through the measured data.
Average DSNU rise under radiation: **20,19 e-/s per Krad @ 25 °C**

This value is in line with the expected value outlined in the detailed specification.
The next graphs display the DSNU histograms during the complete radiation campaign of device 155 (biased) and device 187 (unbiased).

---

**Figure 19. DSNU distributions during TID irradiation biased device 155**
4.3.3.2.2.1.5.5 Temporal Noise
The next two curves display the Temporal Noise versus the TID irradiation for the several reset modes and readout methods measured with the internal ADC.

**Figure 20. Temporal Noise DR INT ADC versus TID irradiation**

**Figure 21. Temporal Noise NDR INT ADC versus TID irradiation**
4.3.3.2.1.5.6  Pixel Response Non Uniformity
The curve below displays the average Local and Global PRNU.

\[
\text{PRNU Soft Reset versus TID irradiation}
\]

![Graph showing PRNU Soft Reset versus TID irradiation](image)

*Figure 22. Local and Global PRNU versus TID irradiation*

4.3.3.2.1.5.7  Column offset behaviour in DR during irradiation
The column offset parameter is not measured in this campaign, but is measured by ESA in a separate low dose TID irradiation campaign. Three devices used for this test are not selected from the evaluation lot but were from a previous unscreened lot.

The low-dose rate radiation test was performed on two HAS devices to monitor the performance deterioration of the APS devices under a radiation environment more representative of that they would be exposed to in space. Previously, the total ionizing dose radiation test at the standard test rate was performed in order to characterize the radiation tolerance to the total ionizing dose (approximately 42 Krad in 3 days); however devices are exposed to the radiation at lower rate for a much longer period of time in a real space environment. Hence, the objective of the low dose rate radiation test is to evaluate the device in a more representative space environment. Two samples were irradiated at very low level of 1 krad/month for a long duration of time (12-15 month) using Co-60 source at ESTEC radiation facility. A third device was used as the control device.

Device 17 was used as witness device.

Device 23 received a 12 Krad TID irradiation. Device 31 received a 15 Krad TID irradiation.
The graph below displays the column offset behaviour versus the TID irradiation.

As shown in Figure 23, the column offset increases as the total ionizing dose increases for both HAS 0023 and HAS 0031. The linear relation of Column Offset (DC) to Total Dose (Krad).

\[
\begin{align*}
\text{Column Offset}_{\text{HAS0031}} (DC) &= 22.44 + 0.45 \times \text{Total Dose} (\text{Krad}) \\
\text{Column Offset}_{\text{HAS0023}} (DC) &= 0.85 + 0.2 \times \text{Total Dose} (\text{Krad}) \\
\text{Column Offset}_{\text{HAS0017}} (DC) &= 0.09
\end{align*}
\]

The results of the long duration low dose rate test indicate that FPN, DC and Column Offset are all affected by the TID and that readout noise is largely unaffected. The relationship between FPN, DC, Column Offset and Total Dose can be approximated by the formulas below:

\[
\begin{align*}
\text{FPN}_{\text{EOL}} (DC) &= \text{FPN}_{\text{BOL}} (DC) + 0.3 \times \text{Total Dose} (\text{Krad}) \\
\text{DC}_{\text{EOL}} (e/p/s) &= \text{DC}_{\text{BOL}} (e/p/s) + 70 \times \text{Total Dose} (\text{Krad}) \\
\text{Col}_{\text{Offset}}_{\text{EOL}} (e) &= \text{Col}_{\text{Offset}}_{\text{BOL}} (e) + 0.45 \times \text{Total Dose} (\text{Krad})
\end{align*}
\]

However, it must be recalled that the Column Offset is not compensated for in the calculation of the FPN and therefore a large part of the observed FPN increase is likely coming from the Column Offset change (in fact the contribution expected would be roughly 1/rt(2) of the Column offset which seems to match the FPN increase observed). It is possible therefore that the FPN is actually not affected at all.

These results can be compared to those from the 42Krad High Dose Rate test detailed in HAS2-CY-FVD-07-013 Issue 1.0 (April 13th 2007). From this comparison it can be noted that in this test we saw a much higher change in FPN wrt TID than in the High Dose Rate test. The high dose rate test showed...
approximately 1 Digital Count change over 14 Krad, this further suggests that the increase seen in this test is actually due to the measurement method and the influence of the Column Offset.

During the low dose rate test a significantly lower rate of increase of dark current was seen than in the high dose rate test (<70 e/p/s/Krad vs. ≈165 e/p/s/Krad). This would indicate that the dark current increase may have a dependency on dose rate.

4.3.3.2.2.1.5.8 Internal Temperature Sensor

Before the total dose irradiation campaign took place, the internal temperature diode of two devices was characterized. The same was done after the 40Krad total dose irradiation campaign. The table below lists the results of the internal temperature sensor calibration. All values are given in volts. As the temperature has a linear behavior with the measured voltage a linear regression is made: Y = C1x +c0 where R gives the goodness of the regression.

Initial measurements:

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>224</td>
<td>1,140</td>
<td>1,417</td>
<td>1,668</td>
<td>1,507</td>
<td>-4,219m</td>
<td>0.997</td>
</tr>
<tr>
<td>227</td>
<td>1,107</td>
<td>1,390</td>
<td>1,641</td>
<td>1,479</td>
<td>-4,266m</td>
<td>0.996</td>
</tr>
</tbody>
</table>

Post measurements after 40Krad:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Vhot [V]</th>
<th>Vroom [V]</th>
<th>Vcold [V]</th>
<th>C0 [V]</th>
<th>C1 [V]</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>224</td>
<td>1,139</td>
<td>1,416</td>
<td>1,670</td>
<td>1,507</td>
<td>-4,240m</td>
<td>0.998</td>
</tr>
<tr>
<td>227</td>
<td>1,101</td>
<td>1,387</td>
<td>1,642</td>
<td>1,478</td>
<td>-4,300m</td>
<td>0.997</td>
</tr>
</tbody>
</table>

As a result we can state that radiation has no influence on the behaviour of the internal temperature diode.

4.3.3.2.2.1.6 TID test campaign conclusion

Except from some small issues we can state that the total dose irradiation campaign was successful. The most valuable parameters (DC and DSNU) were in line or even better than the expectations:

- Average dark signal rise under radiation: 165.78 e-/s per Krad @ 25 °C
- Average DSNU rise under radiation: 20.19 e-/s per Krad @ 25 °C

The devices that were radiated up to 300Krad were still functioning properly but were impossible to measure in the tester due to parameter drifts (DC). At these doses, the dark current and DCNU become so high that sensible operation of the device as an imager is only possible with significant cooling and/or very short integration times.

4.3.3.2.2 Subgroup 2Bii – Proton radiation test

4.3.3.2.2.2 Introduction

The proton irradiation tests were performed in the frame of the evaluation test program for the HAS2 device. The irradiations were performed at the proton irradiation facility in Louvain La Neuve (BE) on March 7th, 2007.
The hardware, firmware and software to bias and drive the components during irradiation were developed by Cypress.

4.3.3.2.2.2 Radiation level and dose rates
The purpose of the campaign was to test the HAS2 device for susceptibility to latch-up under proton beam bombardment and to investigate the effects of protons on the image quality. The test plan was consisting of two actions:

- Operate the sensor in the ion beam until at least $4 \cdot 10^8$ protons/cm$^2$ particles were radiated on the sensor surface.
- Capture and store an uninterrupted image sequence at the given radiation.

For each sensor under test the following exposures to radiation were performed under varying test conditions.

### Table 17. Proton radiation table

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>244</td>
<td>62</td>
<td>$4 \cdot 10^8$</td>
<td>60</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.85 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>2.53</td>
</tr>
<tr>
<td>2</td>
<td>237</td>
<td>62</td>
<td>$4 \cdot 10^8$</td>
<td>180</td>
<td>$7.20 \cdot 10^{9}$</td>
<td>$5.55 \cdot 10^{9}$</td>
<td>0.2</td>
<td>0</td>
<td>7.60</td>
</tr>
<tr>
<td>3</td>
<td>250</td>
<td>62</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.95 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>26.70</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>62</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.95 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>26.70</td>
</tr>
<tr>
<td>5</td>
<td>253</td>
<td>30,5</td>
<td>$4 \cdot 10^8$</td>
<td>60</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.95 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>4.35</td>
</tr>
<tr>
<td>6</td>
<td>232</td>
<td>30,5</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>26.70</td>
</tr>
<tr>
<td>7</td>
<td>247</td>
<td>30,5</td>
<td>$4 \cdot 10^8$</td>
<td>180</td>
<td>$7.20 \cdot 10^{9}$</td>
<td>$5.55 \cdot 10^{9}$</td>
<td>0.2</td>
<td>0</td>
<td>13.05</td>
</tr>
<tr>
<td>8</td>
<td>258</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.95 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>45.88</td>
</tr>
<tr>
<td>9</td>
<td>245</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>180</td>
<td>$7.20 \cdot 10^{9}$</td>
<td>$5.55 \cdot 10^{9}$</td>
<td>0.2</td>
<td>0</td>
<td>10.27</td>
</tr>
<tr>
<td>10</td>
<td>243</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$1.95 \cdot 10^{10}$</td>
<td>0.2</td>
<td>0</td>
<td>30.83</td>
</tr>
<tr>
<td>11</td>
<td>251</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$2.25 \cdot 10^{10}$</td>
<td>2.4</td>
<td>30</td>
<td>125.00</td>
</tr>
<tr>
<td>12</td>
<td>248</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$2.75 \cdot 10^{10}$</td>
<td>2.4</td>
<td>45</td>
<td>152.77</td>
</tr>
<tr>
<td>13</td>
<td>268</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$2.25 \cdot 10^{10}$</td>
<td>2.4</td>
<td>30</td>
<td>30.80</td>
</tr>
<tr>
<td>14</td>
<td>256</td>
<td>9.3</td>
<td>$4 \cdot 10^8$</td>
<td>600</td>
<td>$2.40 \cdot 10^{10}$</td>
<td>$3.90 \cdot 10^{10}$</td>
<td>2.4</td>
<td>60</td>
<td>53.40</td>
</tr>
<tr>
<td>15</td>
<td>257</td>
<td>1·10$^4$</td>
<td>$6 \cdot 10^8$</td>
<td>60</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>2.4</td>
<td>0</td>
<td>0.0082</td>
</tr>
<tr>
<td>16</td>
<td>257</td>
<td>1·10$^4$</td>
<td>$6 \cdot 10^8$</td>
<td>60</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>$1.2 \cdot 10^{-4}$</td>
<td>2.4</td>
<td>60</td>
<td>0.016</td>
</tr>
<tr>
<td>17</td>
<td>257</td>
<td>9.3</td>
<td>$1 \cdot 10^8$</td>
<td>60</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>$1.2 \cdot 10^{-4}$</td>
<td>2.4</td>
<td>60</td>
<td>0.066</td>
</tr>
<tr>
<td>18</td>
<td>257</td>
<td>9.3</td>
<td>$1 \cdot 10^8$</td>
<td>60</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>$6.0 \cdot 10^{-4}$</td>
<td>2.4</td>
<td>0</td>
<td>0.066</td>
</tr>
</tbody>
</table>

For test 1 to 14, current monitoring is being performed during the irradiation window to check for latch-up effects. (Results available upon request).

For test 15 to 18, a continuously image movie is grabbed during the irradiation window. (Results available upon request).

All devices subjected to the proton beam were electrically tested according to Table 2 of the detailed specification immediately after the test.

After 6 months room temperature annealing, unbiased, the devices were measured again. A final measurement was performed after 168h high temperature annealing, biased, at 125 deg C.
4.3.3.2.2.2.3 Test results

**Observations during the proton beam exposure**

During the proton irradiation test no major or minor anomalies were observed. During the current monitoring no latch-up was detected.

**Post electrical measurements**

No major anomalies were detected. The parameter drifts (dark current, DSNU) are as expected. Some of the minor drifts are explained more in detail in the following paragraphs.

4.3.3.2.2.3.1 Dark Current

The graph below shows the average dark current behaviour versus proton irradiation exposure.

![Figure 24. Dark Signal versus Proton Irradiation Exposure](image-url)
The graph below displays the dark signal versus annealing for three devices that had high temperature annealing.

![Dark Signal vs Annealing after LIF Radiation](image)

**Figure 25. Dark Signal versus Annealing after LIF radiation**

### 4.3.3.2.2.2.3.2 Dark Current Non Uniformity

The following graph displays the DSNU histograms after proton irradiation for the devices that were used for the basic tests with 600s.

![DSNU distribution after 600 sec proton irradiation](image)

**Figure 26. DSNU distribution after 600 sec proton irradiation**
Figure 27 represents the DSNU before and after high temperature annealing. Only device 243, 247 and 250 were subjected to this annealing.

Figure 27. DSNU versus annealing for odd columns
The annealing between ‘post radiation’ and ‘post 6 month RT anneal’ is done unbiased. The annealing between this point and ‘post high temp anneal’ is performed under biased conditions.

Figure 28 displays the DSNU distributions for device 250 (62 MeV) before and after high temperature annealing.

Figure 28. DSNU distribution for device 250 (62 MeV – 600 sec) before and after annealing
The following observations can be made:

- The effect of radiation is worse after unbiased room temperature annealing. This effect was also visible after the STAR1000 and STAR250 radiation campaign.
- An offset from zero is visible with increasing radiation. The offset is the highest after room temperature annealing. The effect is ‘healing’ itself after high temperature annealing. This offset can be compensated by the on chip PGA offset register.

### 4.3.3.2.2.3.3 Fixed Pattern Noise

As expected the proton irradiation has influence on the FPN of the sensor. The following observations can be made:

- The lower the energy the higher the influence on the FPN value.
- The influence of the proton irradiation on the FPN value is only visible when the reset mode is soft reset. When the reset mode is hard reset or hard to soft reset no influence is visible.

Figure 29 displays the local FPN for the three different reset modes before and after annealing.

![Figure 29. Local FPN odd columns versus annealing](image)

Global FPN shows exact the same behaviour.
4.3.3.2.2.3.4 **PRNU**
No major anomalies or parameter drifts were observed. Figure 30 displays the Local and Global PRNU for soft reset mode before and after annealing.

![Pixel Response Non Uniformity vs Annealing after LIF Radiation](image)

**Figure 30.** Global and Local PRNU odd columns in soft reset mode versus annealing

4.3.3.2.2.3.5 **Temporal Noise**
The following two curves show the temporal noise, for NDR and DR measured with the internal ADC, versus annealing.

![Temporal Noise Destructive Readout INT ADC versus annealing](image)

**Figure 31.** Temporal Noise Destructive Readout INT ADC versus annealing
Figure 32. Temporal Noise Non Destructive Readout INT ADC versus annealing

4.3.3.2.2.4 Electro optical measurements

Spectral Response
The following graph displays the spectral response curve for device 175 before and after proton radiation (62 MeV – 600 sec). As can been seen on the graph, a small degradation (5%) of the response is visible after radiation between 400nm and 650nm. Due to this degradation NCR 22 was raised.

Figure 33. Spectral Response before and after proton irradiation
NCR 22 conclusion:
The 5% degradation is due to a wrong initial measurement. In order to have a good spectral response measurement, the guard ring around the test pixel array should be connected in order to protect the pixels from outside charge injection. The analysis of the test log showed that the initial measurement was performed without this guard ring being connected (connection to Vcc). The light blue curve shown in the graph tries to equal the initially measured spectral response. But as this measurement without guard ring being connected is very unstable, it is difficult to match the initial measured values. Repeat measurements showed no change to the spectral response due to the environmental stresses.

4.3.3.2.2.5 Conclusion
Based upon the results and investigations after the proton test we can conclude that the proton irradiation campaign was successful.

Susceptibility to latch-up:
During these tests no latch-up condition occurred.

Influence on image quality:
During the different irradiation sessions single images and image sequences were taken. These image sequences are available on request in electronic format for further analysis.

4.3.3.2.2.3 Subgroup 2Bii – Single event effects radiation test

4.3.3.2.2.3.1 Introduction
The hardware, firmware and software to bias and drive the components during irradiation were developed by Cypress.

The purpose of this campaign was to test the image sensors for susceptibility to latch-up under heavy ion bombardment and to investigate the effects of heavy ions on the image quality. The test plan was consisting of two actions:

- Operate the sensor in the ion beam until at least $10^7$ ions/cm$^2$ particles were radiated on the sensor surface.
- Capture and store an uninterrupted image sequence at the given radiation.

For each sensor under test these actions were performed under varying test conditions. Three ion beams were chosen upfront:

<table>
<thead>
<tr>
<th>Beam</th>
<th>Energy [MeV]</th>
<th>Range in Si [um]</th>
<th>LET [MeV/mg/cm$^2$]</th>
<th>Incidence angles</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{83\ 25\ K}\ $</td>
<td>756</td>
<td>92</td>
<td>32.4</td>
<td>0; 30; 45; 60; 80</td>
</tr>
<tr>
<td>$^{132\ 26\ Xe}\ $</td>
<td>459</td>
<td>43</td>
<td>55.9</td>
<td>0; 30; 45; 60</td>
</tr>
<tr>
<td>$^{40\ 84\ Ar}\ $</td>
<td>150</td>
<td>42</td>
<td>14.1</td>
<td>0; 30; 45; 60</td>
</tr>
</tbody>
</table>
4.3.3.2.2.2.3.2 Test campaign

For every test an uninterrupted image sequence is being taken for approximately 180 images or 45 sec movie @ 4 images/s. (Results available upon request) Also a current monitoring is being performed to check for latch-up effects.

The total fluence applied to device 80 (Xe beam) was $0.86 \times 10^7$ ions/cm$^2$. The equivalent total dose for this fluence is 4.46 Krad.

The total fluence applied to device 90 (Ar beam) is $4.5 \times 10^7$ ions/cm$^2$. The equivalent total dose for this fluence is 40.2 Krad.

The total fluence applied to device 84 (Kr beam) is $2.6 \times 10^6$ ions/cm$^2$. (Results available upon request) The equivalent total dose for this fluence is 0.58 Krad.

4.3.3.2.2.3.3 Observations

$^{83}Kr$ Beam

- A common SEU effect discovered is the corruption of the read and reset pointers addressing (HAS2 = rolling shutter). When a heavy ion hits the register of the read or reset pointer, the address getting corrupted and the pointer will jump to another position in the image. This effect is also independent from the integration time setting. ➔ for cross section and work around see par. 4.3.3.2.2.3.5

- In test 10a, the readout got corrupted after the 4th image. As the address parameters are only send once per series of frames by the test equipment, the readout was therefore corrupted for the whole image sequence.

- In test 13a, the same effect occurred as in test 10a.

- In test 14b, the heavy ion has hit the register of the multiplexer. The image we noticed after this impact is probably the selection of the internal temperature sensor. ➔ general best practise is to send all sensor information (read address, write address, register settings) to the sensor every frame or every line (in the row overhead time).

- Another effect we noticed is the visibility of the image lag in soft reset. When the incidence angle was 0 degrees (beam perpendicular on the silicon) the image lag was clearly visible. But
the image lag was less visible with increasing angle. A further investigation is needed to explain this phenomenon. The image lag also disappeared when applying a hard reset instead of a soft reset.

- The expectation was that the spot size of the beam would increase with increasing angle. This was not the case. The spot size only became bigger with an incidence angle of 80 degrees. The left picture below shows a spot size at 0 degrees angle. The right picture shows a spot size at 80 degrees angle.

![Figure 35. Heavy ion resulting spot sizes](image)

$^{132}_{26} Xe$ Beam

- A common effect is the corruption of the read and reset pointers addressing (HAS2 = rolling shutter). When a heavy ion hits the register of the read or reset pointer, the address getting corrupted and the pointer will jump to another position in the image. This effect is also independent from the integration time setting.

- In test 24 the dark offset parameter got corrupted (increasing) after approximately 50 images.

$^{150}_{8+} Ar$ Beam

A common effect is the corruption of the read and reset pointers addressing (HAS2 = rolling shutter). When a heavy ion hits the register of the read or reset pointer, the address getting corrupted and the pointer will jump to another position in the image. This effect is also independent from the integration time setting.

- In test 31 the dark offset parameter got corrupted (increasing) after approximately 50 images.

4.3.3.2.3.4 Test results

After the heavy ion campaign the three sensors used, ID. 80, 84 and 90, were being tested according to Table 2 of the detailed specification.

After 6 months room temperature annealing, unbiased, the devices were measured again. A final measurement was performed after 168h high temperature annealing, biased, at 125 deg C.
4.3.3.2.3.4.1 Dark Current
Figure 36 displays the dark signal versus radiation and annealing after high temperature annealing.

![Dark Signal vs Annealing after HIF Radiation](image)

**Figure 36. Dark Signal versus Annealing**

4.3.3.2.3.4.2 Dark Current Non Uniformity

![Dark Signal Non Uniformity vs Annealing after HIF Radiation](image)

**Figure 37. DSNU versus annealing after HIF radiation**

The annealing between ‘post radiation’ and ‘post 6 month RT anneal’ is done unbiased. The annealing between this point and ‘post high temp anneal’ is performed under biased conditions.

The following observations can be made:
The effect of radiation is better after unbiased room temperature annealing. This is the opposite effect in comparison with the annealing after proton radiation.

An offset from zero is visible with increasing radiation (Xe beam only). The offset is the highest immediately after radiation. The effect is ‘healing’ itself after room & high temperature annealing. This offset can be compensated by the on chip PGA offset register.

**Figure 38. DSNU distribution for device 80 (459 MeV) before and after annealing**

**4.3.3.2.3.4.3 Fixed Pattern Noise**
As expected the proton irradiation has influence on the FPN of the sensor. The following observation can be made:

- The influence of the proton irradiation on the FPN value is only visible when the reset mode is soft reset. When the reset mode is hard reset or hard to soft reset no influence is visible.
Figure 39 displays the local FPN for the three different reset modes before and after annealing.

Figure 39. Local FPN versus annealing after HIF radiation

Global FPN shows the same behaviour.

4.3.3.2.2.3.4.4 Pixel Response Non Uniformity
No major anomalies or parameter drifts were observed.

Figure 40 displays the Local and Global PRNU for soft reset mode before and after annealing.

Figure 40. Global and Local PRNU odd columns in soft reset mode versus annealing

The following observation can be made:

- Device 80 has a remarkable increase in PRNU after being radiated. This increment is due to the influence of the dark current. The effect is healing itself completely after room and high temperature annealing.
4.3.3.2.3.4.5 Temporal Noise

The following two curves show the temporal noise, for NDR and DR measured with the internal and ADC, versus annealing.

![Temporal Noise Destructive Readout INT ADC versus annealing](image1)

**Figure 41. Temporal Noise Destructive Readout INT ADC versus annealing**

![Temporal Noise Non Destructive Readout INT ADC versus annealing](image2)

**Figure 42. Temporal Noise Non Destructive Readout INT ADC versus annealing**

The following observations can be made:
- The temporal noise figures for the internal ADC are not changing dramatically due to the irradiation. A small increment is visible in device 80, but this effect is healing after room and high temperature annealing.
In comparison with the external ADC a clear difference is visible for the different types of reset when using the internal ADC.

- The increment of temporal noise of device 80 is more visible when using the external ADC instead of internal ADC.
- Temporal noise is healing after room and high temperature annealing.

4.3.3.2.3.5 Conclusion

3 Devices were tested against heavy ions. All three tests were completed successfully.

Susceptibility to latch-up:
During these tests no latch-up condition occurred. The HAS2 device is latch up free up to 79.1 MeV/cm².mg with an effective penetration range of 30 µm. In addition, no SEFI requiring HAS power off has been observed during the whole test campaign.

Influence on image quality:
During the different irradiation sessions image sequences were taken. These image sequences are available on request in electronic format for further analysis.

When the HAS2 device is operated with Y address register programmed every frame, image corruption is observed under heavy ions flux. The integration time looks not fully constant within some single frames. This behaviour is likely due to Y address pointers errors inducing modification of the integration time on portion(s) of the image. Corrupted images have been counted and cross section has been extracted. The cross section can be plotted versus the applied heavy ion effective LET.
SEU rate prediction is given in the table below.

<table>
<thead>
<tr>
<th>LEO trapped protons</th>
<th>GEO GCR (M=3)</th>
<th>GEO Solar protons</th>
<th>GEO Solar Ions (M=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2x10^{-4} evt/day</td>
<td>2.6x10^{-4} evt/day</td>
<td>3.2x10^{-5} evt/day</td>
<td>9.3x10^{-2} evt/day</td>
</tr>
</tbody>
</table>

In tracking mode, the SEU will affect one tracking window in a single frame. The SEU rate of the corrupted data can be neglected compared to proton parasitic impacts experienced in the pixel array of the HAS.

As stated above, the observed errors are likely due to SEU in the shift registers. When the HAS2 device is addressed line per line, this behaviour is removed. Cross section should be reduced in this case by a factor of 1024, and even less because the row blanking time is very short.

Additional upset have been observed probably related to resistors upsets: offset shifts, change of output multiplexer address… The cross section of these events is very low. Moreover, such events are significantly reduced by programming the registers every frame.

This appendix describes the possibility to reduce the effect of corrupted images during heavy ion bombardment by implementing a special readout sequence in the device controller. For both DR and NDR mode the following timing can be used:
The effect of corrupted images can be reduced to a corruption of a single line by uploading the address parameters per line. This can be done by uploading the parameters before the SYNC_Y pulse.

### 4.3.3.2.3 Construction analysis

Construction analysis was performed by ESTEC on 3 samples of HAS. It consists of:
- External visual inspection
- Radiographic inspection
- Physical dimensions check
- Die alignment and lateral position
- PIND testing
- Hermeticity testing
- Pin Integrity
- RGA (Residual Gas Analysis)
- Internal Visual Inspection
- SEM inspection
- Bond strength test
- FIB analysis (Focused Ion Beam)
- Microsection
- Materials analysis
- Die attach

<table>
<thead>
<tr>
<th>description</th>
<th>min</th>
<th>typ</th>
<th>max</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>t₁  SYNC_Y* setup</td>
<td>50 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₂  CLK_Y* high width</td>
<td>100 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₃  CLK_Y* period</td>
<td>200 ns</td>
<td></td>
<td></td>
<td>no constraint on duty cycle</td>
</tr>
<tr>
<td>t₄  address delay</td>
<td>30 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₅  setup to next blanking</td>
<td>100 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The following results were reported:

Table 20. Constructional analysis results

<table>
<thead>
<tr>
<th>Test</th>
<th>Condition</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>External visual inspection</td>
<td>ESCC 2059000</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Physical dimensions</td>
<td>Data Sheet</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Radiographic inspection</td>
<td>ESCC 2099000</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>PIND test</td>
<td>MIL-STD-883 method 2020 cond A</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Hermeticity</td>
<td>MIL-STD-883 method 1014</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>RGA</td>
<td>MIL-STD-883 method 1018 proc 1</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>De-cap</td>
<td>Laboratory techniques</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Internal visual inspection</td>
<td>ESCC 2049000</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>SEM inspection</td>
<td>Laboratory techniques</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Bond strength</td>
<td>MIL-STD-883 method 2011</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Microsection</td>
<td>Laboratory techniques</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>Materials analysis</td>
<td>Laboratory techniques</td>
<td>Satisfactory</td>
</tr>
</tbody>
</table>

4.3.3.2.3.1 Hermeticity

The limit for fine leak used at the ESTEC laboratories is $5 \times 10^{-8}$ atm cm$^3$/s. During the previous evaluation campaign of the STAR1000 and STAR250 it was agreed to use a limit of $5 \times 10^{-7}$ atm cm$^3$/s as the device is semi-hermetic. The same limit is used for the evaluation campaign of the HAS2.

Table 21. Conditions for fine leak testing

<table>
<thead>
<tr>
<th>Volume of package (V) in cm$^3$</th>
<th>Bomb condition</th>
<th>R$_1$ Reject limit (atm cc/s He)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum exposure time hours (t$_1$)</td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>75</td>
<td>2</td>
</tr>
<tr>
<td>≥0.05 - &lt;0.5</td>
<td>75</td>
<td>4</td>
</tr>
<tr>
<td>≥0.5 - &lt;1.0</td>
<td>45</td>
<td>2</td>
</tr>
<tr>
<td>≥1.0 - &lt;10.0</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>≥10.0 - &lt;20.0</td>
<td>45</td>
<td>10</td>
</tr>
</tbody>
</table>

The calculated HAS2 cavity volume is 0.507 cm$^3$. This value is on the edge of limit $5 \times 10^{-8}$ atm cm$^3$/s and limit $1 \times 10^{-7}$ atm cm$^3$/s. So the value of $5 \times 10^{-7}$ atm cm$^3$/s is in this case justified.

4.3.3.2.3.2 RGA

The RGA tests done at ORS (outsourced by ESTEC) showed a 7% moisture level inside the cavity. As the limit is only 0.5% this was raised as a Major NCR. There are several potential causes for the high moisture content:

- Individual components (Silicon, ceramic, glass)
- Epoxies (die epoxy, glass epoxy)
- Assembly process flow
A test assembly was manufactured using different materials, which resulted in moisture levels between 0.07% and 1.7%. It was concluded that probably something went wrong during the assembly of the evaluation batch, and that RGA will be part of the assembly lot acceptance test.

In parallel a cycling around dew point test was done (240 cycles between +10°C and +70°C; 1h cycle). The purpose of this test is to demonstrate that the high moisture content does not harm the sensor. Detailed visual inspection showed no signs of corrosion. This conclusion is supported also by the absence of corrosive gasses in the RGA report.

During the first flight assembly lot and the glass lid revalidation tests (see par. 4.4.3), again a high moisture content was observed. As this assembly was witnessed by both Cypress and ESA, the earlier conclusion of an assembly error is not correct. A new NCR was initiated, and new investigations are done consisting of:

- A new test assembly with process variations
- Additional testing to demonstrate the suitability of the devices with high moisture content
- Investigation of the RGA test method to exclude any influence from the RGA test.

The conclusions of the additional investigations are:

- An optimization of the bake-out conditions results in a significantly lower moisture level
- A cycling around dew point test on un-biased devices shows no degradation (this was already demonstrated on biased devices in the evaluation program, see par. 4.3.3.2.4.8)
- The temperature of the RGA test influences the moisture level result. However this is the standard method and will not be changed.

4.3.3.2.4 Package tests

The purpose of package tests is to test the assembly configuration (combination of package, die and glass lid) by stressing it thermally, mechanically and environmentally.

4.3.3.2.4.1 Thermal shock and Thermal cycling

Thermal cycling and thermal shock are done 100 cycles/shocks in stead of 10 (ESCC9020 qualification). However an intermediate test (electrical + fine and gross leak) is done after 10 cycles/shocks. The intermediate test shows whether the devices will survive the 9020 qualification requirements.

10 shocks + 90 shocks [-55°/+125°] were performed on 4 devices. No failures or changed characteristics were noted.

10 cycles + 90 cycles [-55°/+125°] were performed on the same devices as the thermal shock. Thermal cycling is done in a thermal chamber without biasing the devices. No failures or changed characteristics were noted.

4.3.3.2.4.2 Solderability

In this test the solderability of the pins using tin lead eutectic solder is verified (MIL-STD-883 method 2003). 3 electrical rejects were tested. No failures or problems were noted. However wave or reflow soldering is not allowed due to the thermal restrictions of the glass lid epoxy (see paragraph 4.3.3.2.4.6 “resistance to soldering heat”).

4.3.3.2.4.3 Marking performance

The marking performance test verifies the resistance to solvents of the marking on the backside of the sensor (ESCC 24800). 3 electrical rejects were tested. No failures or problems were noted.
4.3.3.2.4.4 *Lid torque*

The lid torque was tested in accordance with MIL-STD-883, method 2024. This test was performed at the ESTEC laboratories and its outcome was successful. See par. 4.3.1.11.4. See also par. 4.4.7 for glass lid torque tests on the updated glass lid.

4.3.3.2.4.5 *Terminal strength*

The terminal strength test verifies the mechanical strength of the pins and the resistance to metal fatigue by applying a repeated bending of the pins (MIL-STD-883 method 2004 condition B2). 3 electrical rejects were tested. No failures or problems were noted.

4.3.3.2.4.6 *Resistance to soldering heat*

The resistance to soldering heat test consists of a soldering dip during several seconds (MIL-STD-750, method 2031). This test was done on 2 devices. One device had the glass coming off during this test. Electrically both parts were ok. The outcome of this test was known upfront. As the Tg value of the die attachment glue is only 171 degrees Celsius, precautions (special soldering scheme) should be taken when soldering the device. Therefore the outcome of this test is not considered to be a problem as the precautions were not taken during this test.

The soldering scheme that is also used for STAR250 and STAR1000 is a proven solution to prevent for glass lid de-attachment.

4.3.3.2.4.7 *Moisture resistance*

For the moisture resistance test, the devices are kept in a moisture chamber with a cycling relative humidity (MIL-STD-883 method 1004). In total 20 cycles are applied on 4 devices. Afterwards the devices are tested electrically and for fine and gross leak. One device failed gross and fine leak. NCR14 covers this problem, and it was also included in NCR21.

4.3.3.2.4.8 *Cycling around dew point*

All devices shall be subject to a cycle around dew point, biased. The number of cycles shall be continuously during ten days and the cycle time conforming to MIL-STD-883 method 1004 (3 °C per minute). The temperature limits shall be chosen to assure that the dew point is covered. The dew point is determined in the constructional analysis (HAS2-CY-FVD-07-020). A seal test and electrical measurements are executed after the 20 cycles.

The RGA testing done during the construction analysis showed a moisture level inside the package of 7% or 70,000PPM which is equal to a dew point of 37,9 °C. Based on this result the temperature limits for the test were chosen as follows:

\[ T_{\text{low}} = 10 \, ^\circ\text{C} \]
\[ T_{\text{high}} = 70 \, ^\circ\text{C} \]

Fine and gross leak test, table 2 electrical test and detailed visual inspection showed no anomalies. The detailed visual inspection was especially dedicated to look for corrosion on any part inside the cavity (silicon, bond wires, finger pads).

As there are no corrosive gasses inside detected at RGA, and cycling around dew point shows no degradation, it can be concluded that the high moisture content has no reliability impact on the image sensor.

4.3.3.2.4.9 *Low temperature storage test*

2 devices are submitted to a -80°C environment for 48h unbiased. Fine and gross leak test, table 2 test and visual inspection showed no anomalies.
4.3.3.2.4.10 Mechanical tests

The devices for mechanical testing are inspected, electrically tested and tested for gross/fine leak both before and after applying the stresses. Because the devices don’t fit in the tester anymore after connecting to the mechanical holder (impossible to remove), the electrical test after the stress is only a short basic test (grabbing an image) to demonstrate that all connections are still functional.

4.3.3.2.4.10.1 Mechanical vibration

3 devices were subjected to the test using MIL-STD-883 Method 2007, test condition A. The vibration level was:

20g from 80Hz to 2000Hz with a maximum displacement of 0.06 inch in the 3 axes.

In total 120 sweeps were performed divided in 3 (difference in axes) times 40 sweeps. No anomalies were seen and all 3 devices passed fine and gross leak test. An additional on 1 device (test-to-destruction - max 50g) also showed no anomalies or failures.

4.3.3.2.4.10.2 Mechanical shock

All devices were subjected to the test using MIL-STD-883 Method 2002, test condition B. The shock level was 1500g with duration of 0.5ms, ½ sine. All devices were being tested in three different axes. Per axis 50 pulses were applied. No anomalies were seen. During leak test 1 device failed marginally for fine leak test (NCR16). An additional test on 1 device (test-to-destruction, max 3000g) showed no anomalies or failures. See also par. 4.4.2 for results on devices with the updated glass lid.

4.3.3.2.4.10.3 Constant acceleration

5 devices were subjected to the test using MIL-STD-883 Method 2001, test condition D. The acceleration level was different (PASS condition), each for 1 minute in the Z-axis.

<table>
<thead>
<tr>
<th>Device ID</th>
<th>Acceleration level</th>
<th>Visual Inspection</th>
<th>Fine &amp; gross leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>5000 G</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>104</td>
<td>11000 G</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>16</td>
<td>15000 G</td>
<td>FAIL</td>
<td>FAIL</td>
</tr>
<tr>
<td>116</td>
<td>15000 G</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>129</td>
<td>21000 G</td>
<td>PASS</td>
<td>PASS</td>
</tr>
</tbody>
</table>

1 device failed because of detachment of the glass lid. NCR17 was raised.

2 devices were tested until destruction by gradually increasing the acceleration level (max. 30000g). 1 device failed at 25000g (completely destroyed), 1 device survived 30000g.

Devices with the updated glass lid (see par. 4.4) passed the 20000g acceleration test.
4.3.3.2.5 Electrical tests

4.3.3.2.5.1 ESD sensitivity

The tests are performed conform to JESD-A114D using the Human Body Model (HBM) and in accordance with ESCC basic specification 23800. This test was outsourced by Cypress to “Maser Engineering” in Holland. The next table lists the results of all measurements:

<table>
<thead>
<tr>
<th>Device s/n</th>
<th>Test</th>
<th>250V Results</th>
<th>300V Results</th>
<th>400V Results</th>
<th>500V Results</th>
<th>1000V Results</th>
<th>2000V Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>137</td>
<td>HBM</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (24)</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>138</td>
<td>HBM</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (12(sh), 23(sh))</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>139</td>
<td>HBM</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (12(sh), 24)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>140</td>
<td>HBM</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (12(sh), 21(sh), 23(sh), 24)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The results were in line with the expectation. According to the results the HAS2 can be catalogued as a CLASS-1A device. The failed pins are outputs from the ADC and the digital supply of the ADC.

4.3.3.2.5.2 Characterization vs. power supply voltage

The devices are tested with variations in different power supplies. Changing power supplies has impact on the functionality and the performance of the device, but no unexpected results were observed. The detailed results are available in the HAS2 evaluation test report. The use of alternative voltages is to be avoided.

4.3.3.3 Endurance tests (Group 3)

An endurance test was executed on 15 devices, at 125 °C for 2000h with intermediate measurements at 168h, 500h and 1000h. 3 samples were measured electro-optically before and after the test:

- Spectral response
- Electro-optical response
- MTF

Taken into account the standard deviation of the test results, no significant changes were observed in any of the characteristics of the table 2 test. The test was performed at room temperature, low temperature (-40C) and high temperature (+85C). The detailed electro-optical measurements showed no change for electro-optical response and MTF. The Spectral response was slightly lower after the life test. This is considered to be a measurement issue (NCR23).
4.4 Glass lid change

As a result of the unstable glass-ceramic bonding (NCR021) a minor change on the glass lid was made. As the bonding between epoxy and AR coating is confirmed to be weak and unpredictable, the new glass lid has a coating free border.

The following paragraphs describe the revalidation tests that have been done.

4.4.1 Glass lid pull test

The lid pull test was performed by the assembly house on 3 empty packages assembled with the new glass lid.

The results of the lid pull test are:

- Glass lid 1: 482N Glass lid came off partially from the ceramic.
- Glass lid 2: 496N Mechanical stud detached from glass lid
- Glass lid 3: 554N Glass lid came off partially from the ceramic

The initial tests were done in phase 1 of the project as a pre-validation. The initial results were 230N and 397N. The average pull force was higher with the new assembled devices due to the better bonding between glass lid and ceramic. It is also clear that the stud was attached in a better way than the previous lid test which had the result that we were able to pull off the glass lid from the ceramic. A good adhesion of the stud to the ceramic and the glass lid will lead to a consistent failure mode (no clear weakest joint surface). This test confirms that the new configuration gives at least the same results as the old configuration. The actual level will be around 500N as with this level the glass lid was detached from the ceramic.

The fact that the glass lid didn’t come off in one part gives a good confidence on this new configuration.

4.4.2 Mechanical shock

For the initial test, see par. 4.3.3.2.4.10.2.

3 devices (Id. 56, Id. 58 and Id. 70) were submitted to the test using MIL-STD-883 Method 2002, test condition B. The shock level is 1500g with duration of 0.5ms, ½ sine, 3 axes, 50 pulses per axis. To simulate the high g powers during the space crafts take-off a destruction test was performed. All devices were subjected to 2000g and 3000g in Z and X or Y axes. In total 4 pulses were applied. Before and after the test the devices were tested for fine and gross leak followed by a detailed visual inspection. No anomalies were observed. Fine leak test showed all devices to be around the limit of 5.00•10^-7 atms. cm^3/s with one device failing marginally.

4.4.3 RGA

RGA test showed 4% of moisture inside the cavity. This means that the improvement actions that were defined based on the evaluation test results are not effective. Additional tests and investigations have been performed. (see par. 4.3.3.2.3.2 and 4.5.24).

4.4.4 Moisture resistance

For the initial test, see par. 4.3.3.2.4.7.

2 Devices were submitted to the test in accordance with MIL_STD-883 method 1004 condition B (240h at 85/85 unbiased).

Electrical test before and after the stress test shows similar results. No failure or parameter drift was noticed. The devices also passed fine and gross leak testing.

This test was performed because there was a failure during the evaluation campaign (NCR14). Retest with the new configuration showed a 100% success.
4.4.5 Thermal shock
For the initial test, see par. 4.3.3.2.4.1.
2 Devices were submitted to the test in accordance with MIL-STD-883 method 1011 test condition B. In total 15 thermal shocks were executed (-55°C, +125°C).
Electrical test before and after the stress test shows similar results. No failure or parameter drift was noticed.
This test was performed to test the devices resistance against aggressive temperature changes. The leak test and electrical test showed no failures.

4.4.6 Mechanical constant acceleration
For the initial test, see par. 4.3.3.2.4.10.3.
3 Devices were submitted to the test using MIL-STD-883 Method 2001, test condition C. The acceleration level was set to 20,000g (PASS condition). Every run took 1 minute in the Z-axis.
Electrical test before and after the stress test shows similar results. No failure or parameter drift was noticed. The devices passed gross and fine leak testing.
This test was performed to test the adherence of the glass lid to the ceramic package. This test showed that the current configuration is acceptable for space flights.

4.4.7 Glass lid torque
For the initial tests, see par. 4.3.3.2.4.4.
The lid torque test was conducted in accordance with MIL-STD-883, test method 2024 and was performed on 4 devices. 2 of the 4 devices were the devices used in the moisture resistance test.
The maximum torques registered by the gauge were as follows:
- Device 48: 13,5 NM (Glass lid crunched)
- Device 49: 20 NM (Glass lid crunched; ceramic package fractured)
- Device 61: 18,5 NM (Glass lid crunched)
- Device 76: 13,5 NM (Glass lid crunched)
In comparison with the old glass lid configuration where the glass lid came off the ceramic package in one piece, the glass lid in the new configuration was completely crunched after been submitted to the torque test. It clearly shows a good bond between the glass lid and the ceramic. No weak points between glass lid and epoxy or ceramic and epoxy has been observed with this new package configuration. The seal area was calculated as 9 to 10 square mm for which the Mil Std gives a recommended minimum shear force of 12.8 Newton meters. The results for these parts are considered satisfactory.

4.4.8 Conclusion
The new glass lid configuration has proven its suitability for space flights. In comparison with the old configuration the moisture resistance test and mechanical constant acceleration both succeeded the MIL testing.
The high moisture content is still considered to be a problem, and this is under further investigation. The reason for changing the glass lid was to get a reliable glass bonding, and this is successful.
4.5 NCRs

4.5.1 NCR1: Low assembly yield
The assembly of the evaluation showed a high reject rate when using FM requirements. Most rejects are due to particles inside the cavity.
Main cause of particles showed to be the glove box. The following measures were taken:
• Replacement of the rubber gloves
• Particle filter at N2 intake
It was also decided to witness all FM assembly jobs.
The several test assembly jobs and the first FM assembly job showed that the problems are solved.
Class: minor
Status: closed

4.5.2 NCR2: Temporal noise measurement not correct
The test set-up showed incorrect results for temporal noise.
Investigation showed that a bug in the test software caused this.
The bug was fixed.
Class: minor
Status: closed

4.5.3 NCR3: Test system ADC settings not correct
The test system ADC setting are not correct.
This was caused by a fault in the test software.
Devices that were already measured and are in stress will be remeasured with both the old (comparison) and new settings.
Class: minor
Status: closed

4.5.4 NCR4: glass lid adhesion
Glass lid detached after dropping a sensor incidentally on the table top.
This is covered by NCR21 on glass lid attachment.
Class: minor
Status: closed

4.5.5 NCR5: overcurrent problem at +85C
Some devices show an overcurrent at +85C.
The reason is not clear, but devices with this phenomena will be captured during FM screening. An operational test at +85C is included in the screening as standard screening test.
Class: minor
Status: closed

4.5.6 NCR6: FPN decreasing with increasing radiation
During total dose radiation test, the FPN is decreasing with increasing radiation in hard to soft reset mode.
Use as is.
Class: minor
Status: closed
4.5.7 NCR7: Large FPN difference after 20Krad between odd and even columns in Hard to Soft Reset Mode
After 20Krad total dose irradiation there is a significant FPN difference between odd and even columns during hard to soft reset.
Test system issue. Use devices as is.
Class: minor
Status: closed

4.5.8 NCR8: Big spread in INL results
The resulting standard deviation of all INL results measured on devices during the test campaign has a large spread.
This is caused by the test set-up.
A new system, specifically for characterising the ADC is in development.
New results will be used in an updated ICD.
Class: minor
Status: open

4.5.9 NCR9: Increased standby current at high temperature after radiation
Table 2 test after radiation shows an increased standby current at high temperature.
Root cause is not known, use as is.
Class: minor
Status: closed

4.5.10 NCR10: Current failure during thermal resistance test
During thermal resistance measurement, the current required for device heating exceeded the tolerances of the device, essentially destroying the device; as such further measurements on the device could not take place.
This is caused by the test method which uses a power pin protection diode.
As there are 3 valid results, there is no need to repeat the test.
Class: minor
Status: closed

4.5.11 NCR11: Connection problem during burn-in
Burn-in data showed that there was a connection problem resulting in some pins not being biased.
A verification step was included in the burn-in test start. The affected devices have got additional burn-in to compensate for this.
Class: minor
Status: closed

4.5.12 NCR12: RGA test showed 7% moisture
RGA test results show a moisture level of 7% inside cavity. Limit is 0.5%.
This was considered to be caused by a problem during assembly. A test assembly showed good results.
It is known that semi-hermetic devices often have moisture problems, but 1 to 1.5% should be achievable.
Class: major
Status: closed. Afterwards it was shown that the problem was not solved (see NCR24)

4.5.13 NCR13: Glass lid detached during soldering heat test
During the soldering heat test the glass lid detached.
This is caused by the temperature being above Tg of the epoxy. Specific soldering instructions avoid this problem. (see also NCR21)
Class: minor
Status: closed.

4.5.14 NCR14: Fine & Gross leak failure after moisture resistance test
During the leak test after moisture resistance, fine and gross leak failures were identified on 1 device out of 4 that were tested.
This is caused by an unreliable bonding between ceramic and glass. NCR21 covers these issues.
Class: minor
Status: closed (see NCR21).

4.5.15 NCR15: Fine leak failure after mechanical shock test
A fine leak failure was identified on 1 device out of 3 at leak testing after mechanical shock test. The leak test result was marginally out of spec.
This is only a marginal change in leak rate. Use as is. See also NCR21 for overall glass bonding issues.
Class: minor
Status: closed

4.5.16 NCR16: Spectral response equipment failure during initial testing
After initial testing, an error in the setup of the spectral equipment was detected. The Halogen lamp used in the equipment was out of date and was therefore unreliable. The spectral response measurements obtained before burn in are unreliable due to instable behavior of the halogen lamp of the spectral response equipment.
Use as is. This has no significant impact on the program.
Class: minor
Status: closed.

4.5.17 NCR17: Failure at constant acceleration
The glass lid de-attached from the package during the 15.000G constant acceleration test.
See NCR21 for overall glass bonding issues.
Class: minor
Status: closed.

4.5.18 NCR18: Die placement inconsistency after assembly
Placement of the silicon inside the cavity showed some inconsistency compared to the initial requested placement.
Discussed with assembly house and measurement procedure updated. Placement is part of lot acceptance test, and FM devices have 100% measurement in the screening.
Class: minor
Status: closed

4.5.19 NCR19: Glass lid optical performances after MIL 675-C testing
Transmission and reflection curves showed degradations after submission to salinity test. Caused by stains after the test. Mechanical qualities are ok.
Use as is.
Class: minor
Status: closed
4.5.20 NCR20: Inconsistency problems with fine leak results after thermal cycling
Fine leak results increases after thermal cycling.
Root cause is not known, equipment is ok. Correct measurement is possible but not likely.
Use as is. It is however advised to discuss this in the ESCC9020 work group as there are many interpretations of the test method.
Class: minor
Status: closed

4.5.21 NCR21: Glass lid attachment process is not under control
Some individual failures of the glass attachment process have been observed in different tests. It seems the glass lid attachment is most of times ok, but from time to time it fails so it is not under control. It is assumed that there is a unknown parameter influencing the attachment result. NCRs 004, 014, 015 and 017 show minor issues with the glass lid, but overall it shows the process is not under control.
This is caused by the presence of an AR coating, which has a problematic bonding with epoxy. The use of an AR free border on the glass lid has solved this.
Class: major
Status: closed

4.5.22 NCR22: Spectral Response degradation after proton irradiation
A 5% degradation in spectral response was observed after the submission to proton irradiation.
This was caused by a measurement set-up issue.
Class: minor
Status: closed

4.5.23 NCR23: Spectral Response degradation after Life Test
A 5% degradation in spectral response was observed after been submitted to a 2000h life test.
This was caused by a measurement set-up issue.
Class: minor
Status: closed

4.5.24 NCR24: High moisture count in HAS2 flight devices
RGA test on flight devices show 6% to 9% moisture content.
Potential causes:
- Components
- Epoxies
- Assembly flow
- Test procedure
The following investigations have been done or are still ongoing:
- RGA test procedure investigation (done)
  - The results are influenced by the test temperature.
- Moisture behaviour of ceramic package, glass lid and silicon (ongoing)
- Moisture behaviour of die bond epoxy and glass lid epoxy (ongoing)
- Test assembly with several process variations (done)
  - Bake-out time and bake-out temperature have a high influence
  - Epoxy defrost time should be sufficient
- Cycling around dew point (unbiased) to demonstrate that the moisture does not harm the sensor (ongoing).
Class: major
Status: open
5 Conclusion and Lessons Learned

The aim of the project was to do a design update of the HAS sensor and to perform a complete evaluation of the HAS2 sensor in order prove it is suitable for flight missions. The design updated was reduced to a minor update to minimize the risks. A very extensive evaluation test campaign was performed which showed a number of issues, of which the glass lid attachment and the moisture level inside the cavity are the biggest concerns for flight missions. These issues were all investigated and resolved. The glass lid attachment was improvement by doing a minor update on the glass lid configuration. The moisture level has been significantly reduced and is now well controlled and understood and there is additional evidence the excess moisture is, in any case, not harmful to the device.

The test results and design/ process updates resulting from the investigations have demonstrated the HAS2 sensor has good performances and is suitable for flight missions. An EPPL entry has been applied for.

The following lessons were learned during this project:

- The planning of an evaluation project should include enough time for intermediate testing, transportation between test sites should be minimized and allocation provided up front for investigative testing. The planning of an evaluation project should include enough time to execute additional investigations and tests arising due to unexpected results. The best case scenario of being faced with no issues at all will happen only very rarely.
- A pre-validation phase should always be included in the project to test specific items that are possible causes of non-conformity. These pre-validation tests should include variations of process parameters to reach optimal process settings (ref. bake out time and bake-out temperatures).
- The early involvement of potential customers in the evaluation campaign brings large benefits in terms of customer ‘buy in’ and helps efficiency in solving problems arising.
- Radiation effects: We performed a very detailed radiation test including total ionizing dose, proton irradiation and heavy ion bombing. Proton and heavy ion were radiated under different incident angles. This taught us a lot the specific radiation effects for HAS2 which will allow to improve future detectors, but also raised additional questions on unexpected/unexplained effects.
- Project management: Assign a project manager who is independent from the technical people.
6 Annex: Industry ‘wishes for improvements’ for HAS

This section details the decisions / outcome of the industry requests and the related investigations at the end of phase 1. The table gives an overview of all requests with their status:

- “No change to HAS”: request is accepted but does not require a design change
- “Reject”: request is rejected and explanation for it is added
- “Under investigation”: request is under investigation. A decision is pending (see par. 3 for the result)

All requests have an ID with a letter and number:
- A are design aspects
- B are documentation aspects
- C are evaluation testing aspects
- D are packaging aspects
- E are industrial and commercial aspects

<table>
<thead>
<tr>
<th>N°</th>
<th>Description of change/improvement</th>
<th>Investigation Reference</th>
<th>status</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1*</td>
<td>Lag performance</td>
<td></td>
<td>No change to HAS</td>
<td>Will be implemented in test.</td>
</tr>
<tr>
<td>A2*</td>
<td>Characterisation of leakage current</td>
<td></td>
<td>No change to HAS</td>
<td>This is a yield issue related to defects. Not a design issue</td>
</tr>
<tr>
<td>A3*</td>
<td>Column based FPN (average column offset) profile in DS BOL &amp; EOL</td>
<td></td>
<td>Rejected</td>
<td>Caused by the analog power supply for the column structure being connect on one side only. Redesign (connect at both sides) improves a little bit but will not solve the problem. Also this redesign is not feasible without changing the pinout.</td>
</tr>
<tr>
<td>A4*</td>
<td>Sensitivity of background to VDD</td>
<td></td>
<td>Rejected</td>
<td>Sensor array and ADC have an opposite effect. Currently Cypress cannot reproduce any drift with a constant power supply. Cypress recommends to</td>
</tr>
<tr>
<td>N°</td>
<td>Description of change/improvement</td>
<td>Investigation Reference</td>
<td>status</td>
<td>explanation</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>A5*</td>
<td>ADC noise reduction</td>
<td></td>
<td>Rejected</td>
<td>Redesign will improve a little bit, but due to the impact on the schedule (at least 3 months delay) no redesign will be done.</td>
</tr>
<tr>
<td>A6*</td>
<td>Window to window crosstalk</td>
<td>Investigating in progress</td>
<td></td>
<td>Currently Cypress cannot reproduce the problem. The baseline at this moment is no change. Cypress to collect additional information.</td>
</tr>
<tr>
<td>A7*</td>
<td>Inside window crosstalk</td>
<td>Investigating in progress</td>
<td></td>
<td>This is considered to be related to the applied timing.</td>
</tr>
<tr>
<td>A8*</td>
<td>Thermistor dynamic improvements</td>
<td>Rejected</td>
<td></td>
<td>Tailor the thermistor to the used temperature range require an additional amplifier stage and extra calibration. The design will not be changed.</td>
</tr>
<tr>
<td>A9*</td>
<td>Increasing of tolerance to radiation</td>
<td>Rejected</td>
<td></td>
<td>This is very difficult to improve and requires a major redesign. This is not feasible with the current detector and therefore the design will not be changed.</td>
</tr>
<tr>
<td>A10*</td>
<td>Power supply noise influence on output signal</td>
<td>No change to HAS</td>
<td></td>
<td>The PSRR is 25. 100mV change on the power supply has a 300e- change at the output. Improvement requires architectural changes and complete redesign. The design will not be changed and care has to be taken in power supply design.</td>
</tr>
<tr>
<td>A11*</td>
<td>Removal of de-tinning problems</td>
<td>Investigating in progress</td>
<td></td>
<td>A package change is very difficult and not feasible in a short time scale. An epoxy change is under investigation.</td>
</tr>
<tr>
<td>A12*</td>
<td>Lower RGA values to 0.5%</td>
<td>Investigating in progress</td>
<td></td>
<td>Actually 2% for STAR250/STAR1000. this is an epoxy issue, but major improvement is only possible with real hermetic seal. Currently only an epoxy change is under investigation.</td>
</tr>
<tr>
<td>N°</td>
<td>Description of change/improvement</td>
<td>Investigation Reference</td>
<td>status</td>
<td>explanation</td>
</tr>
<tr>
<td>----</td>
<td>----------------------------------</td>
<td>-------------------------</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>A13</td>
<td>Reduce sensitivity to ESD</td>
<td>Investigation in progress</td>
<td>If 250V or better in HBM test, than no change.</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>ICD – All performance: add performance in HTS reset</td>
<td>No change to HAS</td>
<td>HTS (Hard to Soft) reset is baseline HTS + soft reset in rad testing HTS + soft + hard reset in characterisation before and after rad testing</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>ICD – test condition: add HTS reset</td>
<td>No change to HAS</td>
<td>HTS (Hard to Soft) reset is baseline HTS + soft reset in rad testing HTS + soft + hard reset in characterisation before and after rad testing</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>ICD – local/global column to column based FPN in DS</td>
<td>No change to HAS</td>
<td>Document update</td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>ICD – local/global average FPN value within columns (“= pixel FPN with column FPN removed”) in DS</td>
<td>No change to HAS</td>
<td>Document update</td>
<td></td>
</tr>
<tr>
<td>B5</td>
<td>ICD – FPN, PRNU, DCNU defects: characterise and update classification in ICD</td>
<td>No change to HAS</td>
<td>Document update</td>
<td></td>
</tr>
<tr>
<td>B6</td>
<td>Measurement of Lag</td>
<td>No change to HAS</td>
<td>Add lag test to ICD</td>
<td></td>
</tr>
<tr>
<td>B7</td>
<td>Add a specific HAS Measurement method document</td>
<td>No change to HAS</td>
<td>Documentation update</td>
<td></td>
</tr>
<tr>
<td>B8</td>
<td>Specification improvement</td>
<td>No change to HAS</td>
<td>Add disclaimer on the risk of unexpected results when using an alternative timing</td>
<td></td>
</tr>
<tr>
<td>B9</td>
<td>Black register in NDR mode; where in block diagram?</td>
<td>No change to HAS</td>
<td>Document update</td>
<td></td>
</tr>
<tr>
<td>B10</td>
<td>Window to window crosstalk</td>
<td>Investigation in progress</td>
<td>Depends on A6</td>
<td></td>
</tr>
<tr>
<td>B11</td>
<td>Inside window crosstalk</td>
<td>Investigation in progress</td>
<td>Depends on A7</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>Lag test</td>
<td>No change to HAS</td>
<td>Testing update</td>
<td></td>
</tr>
<tr>
<td>C2*</td>
<td>Operating condition</td>
<td>No change to HAS</td>
<td>Ref. B1</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Description of change/improvement</td>
<td>Investigation Reference</td>
<td>status</td>
<td>explanation</td>
</tr>
<tr>
<td>-----</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>-----------------------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>C3</td>
<td>HAS evaluation (characterization after life test and total dose/proton)</td>
<td></td>
<td>No change to HAS</td>
<td>Ref B1</td>
</tr>
<tr>
<td>C4</td>
<td>HAS operating conditions during evaluation (operation during burn-in, life test and total dose)</td>
<td></td>
<td>No change to HAS</td>
<td>Total dose: ON and OFF&lt;br&gt;Proton: ON and OFF&lt;br&gt;Heavy ion: ON&lt;br&gt;Burn-in and life test: ON</td>
</tr>
<tr>
<td>C5</td>
<td>Full frame PRNU (global)</td>
<td></td>
<td>No change to HAS</td>
<td>Test set-up issue</td>
</tr>
<tr>
<td>C6*</td>
<td>Leakage current (VDD_PIX)</td>
<td>A2</td>
<td>No change to HAS</td>
<td>Part of screening</td>
</tr>
<tr>
<td>C7*</td>
<td>Leakage current (other inputs)</td>
<td>A2</td>
<td>No change to HAS</td>
<td>Part of screening</td>
</tr>
<tr>
<td>C8</td>
<td>Voltage on relevant pins for device health check under standby, DS, CDS mode</td>
<td></td>
<td>No change to HAS</td>
<td>ICD document change</td>
</tr>
<tr>
<td>C9</td>
<td>Column based FPN profile in DS BOL &amp; EOL</td>
<td></td>
<td>No change to HAS</td>
<td>Image processing test</td>
</tr>
<tr>
<td>C10</td>
<td>In-house (@ Fillfactory) sensor calibration (for each FM sensor and delivered devices)</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td>• ADC registers programming</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Odd/even OFFSET registers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BLACK register</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Temperature sensor offset and slope (TBC for slope), range : refer to A7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Analogue inputs (input to output curve)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C11</td>
<td>Evaluation of stability of sensor calibration over life (endurance, radiation) for ADC registers programming</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td>• Odd/even OFFSET registers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BLACK register</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Temperature sensor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Analogue inputs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C12</td>
<td>open</td>
<td></td>
<td>No change to HAS</td>
<td>Total dose 50krad</td>
</tr>
<tr>
<td>C13</td>
<td>Proton, total dose RadLAT/evaluation level</td>
<td></td>
<td>No change to HAS</td>
<td>Total dose 50krad</td>
</tr>
<tr>
<td>N°</td>
<td>Description of change/improvement</td>
<td>Investigation</td>
<td>status</td>
<td>explanation</td>
</tr>
<tr>
<td>-----</td>
<td>---------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
<td>--------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>LET level for heavy ions test</td>
<td></td>
<td></td>
<td>Proton same as STAR1000 SEU 110 equivalent LET</td>
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<tr>
<td>C14*</td>
<td>Intermediate shut down of ADC</td>
<td></td>
<td>No change to HAS</td>
<td>Note on how to do this Not recommended.</td>
</tr>
<tr>
<td>C15</td>
<td>Performance characterisation and evaluation (in particular noise, FPN, PRNU)</td>
<td>B1</td>
<td>No change to HAS</td>
<td>HTS reset to be added to test</td>
</tr>
<tr>
<td>C16</td>
<td>open</td>
<td></td>
<td></td>
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<tr>
<td>C17</td>
<td>open</td>
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<td></td>
<td></td>
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<tr>
<td>C18</td>
<td>Temperature sensor calibration accuracy</td>
<td>C10-C11</td>
<td>---</td>
<td>See C10 and C11</td>
</tr>
<tr>
<td>C19</td>
<td>open</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>C20</td>
<td>open</td>
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<tr>
<td>C21</td>
<td>open</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C22*</td>
<td>Low dose rate total dose testing</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
</tr>
<tr>
<td>C23*</td>
<td>Operation of devices (image taking) during all radiation tests</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
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<tr>
<td>C24</td>
<td>Evaluation test (radiation, life test) including leakage current on VDD_PIX</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
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<tr>
<td>C25</td>
<td>Evaluation test (radiation, life test) including leakage current (all other inputs) -</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
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<tr>
<td>C26</td>
<td>Evaluation test (temperature, radiation, endurance) including analogue inputs curve and temperature sensor calibration curve</td>
<td></td>
<td>No change to HAS</td>
<td>OK</td>
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<tr>
<td>D1*</td>
<td>Geometrical die centring wrt to package</td>
<td></td>
<td>No change to HAS</td>
<td>Spec to be defined for CDR</td>
</tr>
<tr>
<td>D2</td>
<td>Geometrical parallelism die wrt to package</td>
<td></td>
<td>No change to HAS</td>
<td>Spec to be defined for CDR</td>
</tr>
<tr>
<td>D3a*</td>
<td>Window deformation under vacuum</td>
<td></td>
<td>Under investigation</td>
<td>Test is ongoing at ESTEC</td>
</tr>
<tr>
<td>D3b *</td>
<td>Window thickness</td>
<td></td>
<td>Under investigation</td>
<td>Test is ongoing at ESTEC</td>
</tr>
<tr>
<td>D4*</td>
<td>Degradation of hermeticity during Tinning/de-golding process</td>
<td>Ref A11 + A12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Description of change/improvement</td>
<td>Investigation Reference</td>
<td>status</td>
<td>explanation</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>--------------------------</td>
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<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>D5*</td>
<td>Package cracks on HAS-BK7 (corners of ceramic) to be analysed for Burn-in boards</td>
<td>Under investigation</td>
<td>Verification of sockets used for burn-in</td>
<td></td>
</tr>
<tr>
<td>D6</td>
<td>Quality of window film on HAS-BK7 (Will not be used for future operation)</td>
<td>Rejected</td>
<td>Window film will not be used anymore.</td>
<td></td>
</tr>
<tr>
<td>D7</td>
<td>Die Flatness</td>
<td>No change to HAS</td>
<td>Spec to be defined for CDR</td>
<td></td>
</tr>
<tr>
<td>D8</td>
<td>Geometrical parallelism die wrt to window</td>
<td>No change to HAS</td>
<td>Spec to be defined for CDR</td>
<td></td>
</tr>
<tr>
<td>D9*</td>
<td>Resistance to internal vapour content (humidity test combined with temperature cycling around dew point)</td>
<td>No change to HAS</td>
<td>Add cycling around dew point to evaluation program</td>
<td></td>
</tr>
<tr>
<td>E1</td>
<td>FM screening including leakage current on VDD_PIX</td>
<td>No change to HAS</td>
<td>FM screening</td>
<td></td>
</tr>
<tr>
<td>E2</td>
<td>FM screening including leakage current (all other inputs)</td>
<td>No change to HAS</td>
<td>FM screening</td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>Voltage on relevant pins for device health check under standby, DS, CDS mode – refer to C8</td>
<td>No change to HAS</td>
<td>Data in FM report</td>
<td></td>
</tr>
<tr>
<td>E4</td>
<td>EM/FM data on in-house (@ Cypress) sensor calibration - refer to A7, C10</td>
<td>No change to HAS</td>
<td>Data in FM report</td>
<td></td>
</tr>
</tbody>
</table>