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RUAG SPACE PROJECT 129.66
CAPS
CUSTOMER REF: ESA

TECHNICAL NOTE
EXECUTIVE SUMMARY REPORT

ORIGINAL
IF RED

Name	Dept.	Date	Signature
EDITED BY:			
P. DAINESI	RSSNP	17.12.15	
PROJECT MANAGER:			
P. DAINESI	RSSNP	17.12.15	
QUALITY ASSURANCE:			
C. RUSCA	RSSNQ	17.12.15	

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16.12.2015	-	Initial Edition	A

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1. INTRODUCTION

This document presents the Executive Summary Report of the “Contactless Angular Position Sensor” project phase IIIa developed within the ESA GSTP6.2 contract n. 4000113131/14/NL/CBi/fk. The aim of this activity was to confirm and verify through a proper test campaign that the whole sensor performances within a Chip On Board (CoB) package were fully successful. In particular following the design modification required to remove the noise issue on chips version V6.8 and implemented in CAPS chips V6.9. This activity included the following tasks:

- Encapsulation of the CAPS chips V6.9 fabricated in the framework of the previous project phase;
- Pre-Evaluation of the CAPS chips V6.9;
- Design and fabrication of a new test board to extend the temperature range of testing to -40°C to +85°C, at ambient pressure.

An additional part of this project (proposed to be covered by the CCN 129.66-01) consisted in the design change required to modify the sensor’s bonding pads to 100x100 μm^2.

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

[AD1] GSTP 6 Element 2: Competitiveness Permanent Open Announcement of Opportunity for Market- Oriented Activities CALL FOR PROPOSALS. - AO/1-7935/14/NL/CB Item no. 14.136.01

[AD2] Special conditions of tender for the general support technology programme (gstp-6) element 2 – competitiveness - appendix 1 to ao/1-7935/14/nl/cbi

2.2 REFERENCE DOCUMENTS

[RD1] Final report on CAPS V6.8 – RUAG document NT-129.66-60 Version B

[RD2] PV-129.66-02 CAPS Technical Meeting_MoM_V2

[RD3] ESCC Generic Specification No. 9000. INTEGRATED CIRCUITS, MONOLITHIC, HERMETICALLY SEALED

[RD4] ESCC Basic Specification No. 2269000. EVALUATION TEST PROGRAMME FOR MONOLITHIC INTEGRATED CIRCUITS

[RD5] ECSS – E ST 33 01C Space engineering Mechanisms

[RD6] Test board User Manual, Ruag doc. NT-129.66-01 revision A

[RD7] Test procedures, RUAG doc. IC-129.66-92 CAPS Pre-eval V6.9 Test procedures

[RD8] Test results, RUAG doc. RE-129.66-14 CAPS v6.9 Pre-eval campaign test results

[RD9] CAPS Final Report RUAG Space doc. NT-129.66-60

[RD10] CAPS V69 datasheet RUAG Space doc. NT-129.66-72

[RD11] CAPS Final Report GSTP6.2 RUAG Space doc. NT-129.66-61

3. ABBREVIATIONS

CAPS	Contactless Angular Position Sensor
CCN	Contract Change Notice
ECSS	European Cooperation for Space Standardization
SOW	Statement of Work
TRL	Technology Readiness Level

4. BACKGROUND

Angular position sensors are requested in numerous space applications, to provide accurate monitoring/control of rotating elements.

For this function in space, the two most used technologies are Optical Encoders and Potentiometers. The optical encoders provide a good contactless solution but are rather big, very expensive and sensitive to environments. The potentiometers, either based on plastic or wire-wound track technologies have both led to noise problem during qualifications. Failures in flight have been reported by Satcom manufacturers and lead to the conclusion that the electro-mechanical contact tribological behavior is not fully mastered yet.

Next future space missions will be more and more challenging, and will require advance angular sensors, meant for longer life time, better accuracy, and will be used under harsher environment.

In the view of this situation, an ESA TRP (contracts number 20404/06/NL/CP) has been initiated, in 2008, with RSSN, to assess the feasibility/functionality of a new type of Cost effective and Contactless sensors based on alternative technology.

Then in 2010 a follow up activity under GSTP (contracts number 22854/09/NL/SFe), for an innovative concept of contactless angular position sensor has been developed, manufactured and tested. Today, the design proposed by RUAG has been optimized with respect to accuracy, packaging, thermal and radiation hardening.

However, the pre-evaluation on chip Version 6.9 and the full Evaluation test campaign and some complementary activities (i.e upgrade au test board) need to be done to reach a higher TRL allowing to put the product on the market. These additional activities should be covered within GSTP 6.2 and ECI programs.

This report summarizes the activities carried on in the framework of the GSTP6.2 project focused on the pre-evaluation of V6.9 CAPS chips; the full report of this activity is available separately [RD11].

5. EXECUTIVE SUMMARY

5.1 PROJECT GOALS

During pre-evaluation of CAPS V6.8 a noise issue has been identified [RD9]. A potential design solution has been identified by the chip manufacturer and this solution was agreed to solve the issue. Consequently an additional design run was launched (CAPS V6.9) with 40 new additional samples to be tested.

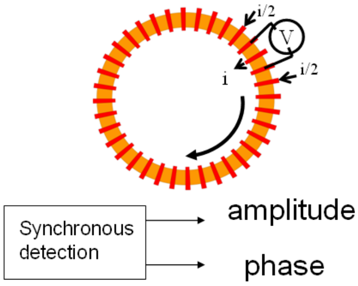
This activity was concluded on November 2014 when the bare dies of CAPS V6.9 were delivered. The dies were then encapsulated and finally 33 CAPS v6.9 chips were available for test

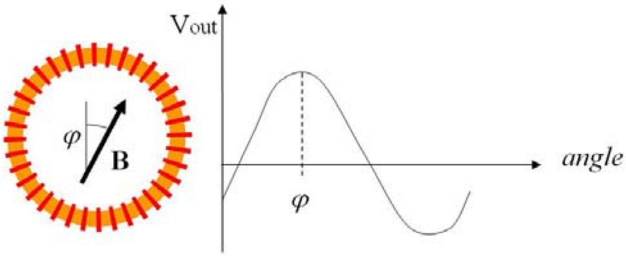
The goal of this activity was to perform a pre-evaluation test campaign on the available chips in order to validate its performances and approve the fabrication of successive 1200 chips to be fabricated and tested under the evaluation program of the ECI activity (project phase IIIb).

A second goal of this activity was to design and fabricate a new test board to allow testing V6.9 chips during the ECI test campaign in the temperature ranges from -40°C to +85°C, at ambient pressure.

5.2 SENSOR DESCRIPTION

The CAPS sensor is based on sensing the angular position of a rotating magnetic field. A circular Hall sensor based design allows for measuring a voltage proportional to the magnetic field and the injected current (see picture below). By sampling at high frequency the voltage over the sensor perimeter a phase shift of the voltage is detected which is proportional to the magnetic field angle. Sampling can be performed clockwise (CW mode) or counter-clockwise (CCW mode).





The excitation and measurement of the hall sensors is performed at a frequency of 100kHz.

5.3 SENSOR DEVELOPMENT

During the previous activities of the project several design updates have been performed and their outcome is reported in the final report of the previous activity [RD9].

The latest design update performed before the fabrication of chips V6.9 was made to get rid of noise on the output, around 90°, in CW configuration.

5.4 UPDATE TO V6.9

On chip V6.8, the outputs were generating noise around 90°, when working in CW mode (default mode). This phenomenon did never happen in CCW mode.

The solution to solve this problem was to "delete" the CW mode and use the CCW mode as default. The CW mode is then regenerated from the CCW mode.

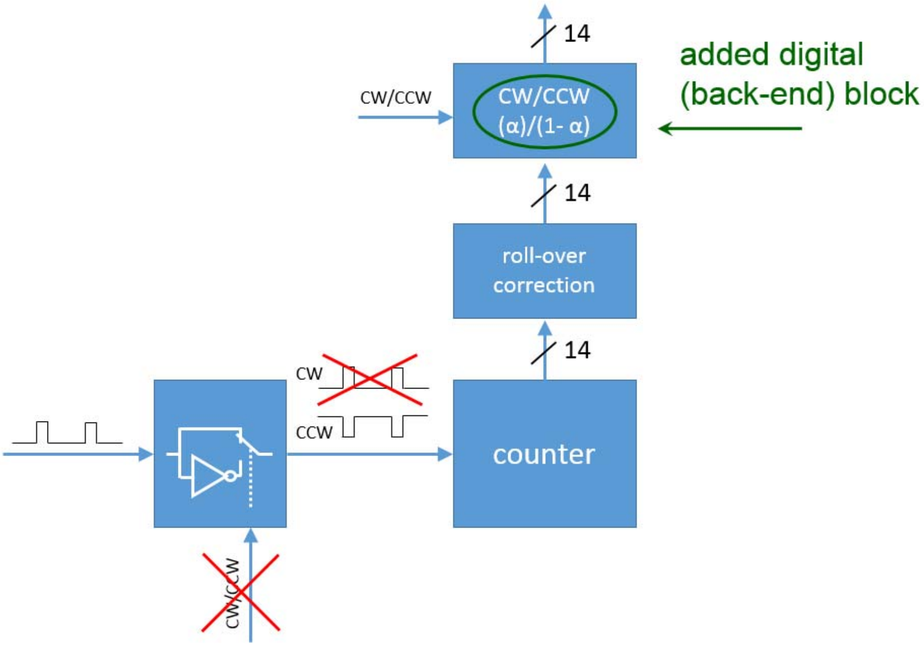


Figure 1 : Block diagram

The initial CW/CCW block is locked to CCW mode. A new block is placed on the back-end to digitally reconstruct the CW mode (see Figure 1).

Figure 2 and Figure 3 show the schematic and the layout of the modified v6.9 design respectively.

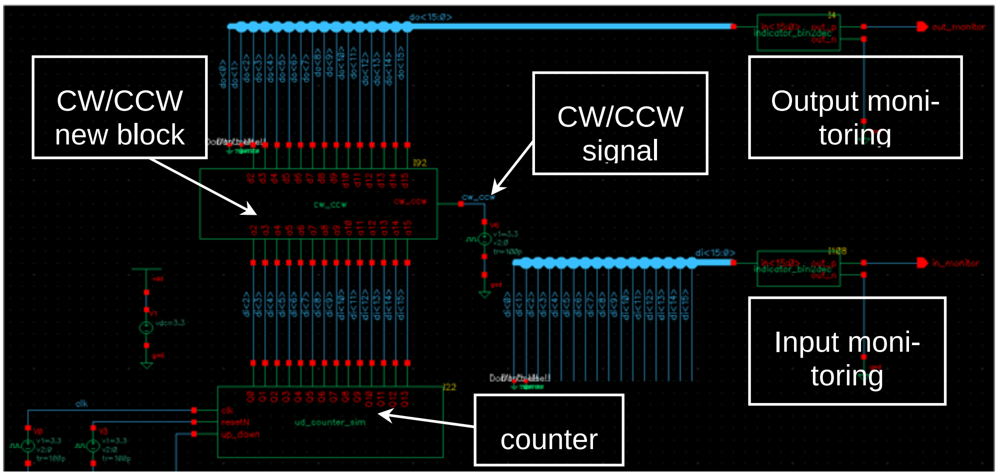


Figure 2: Schematic of CAPS chip V6.9

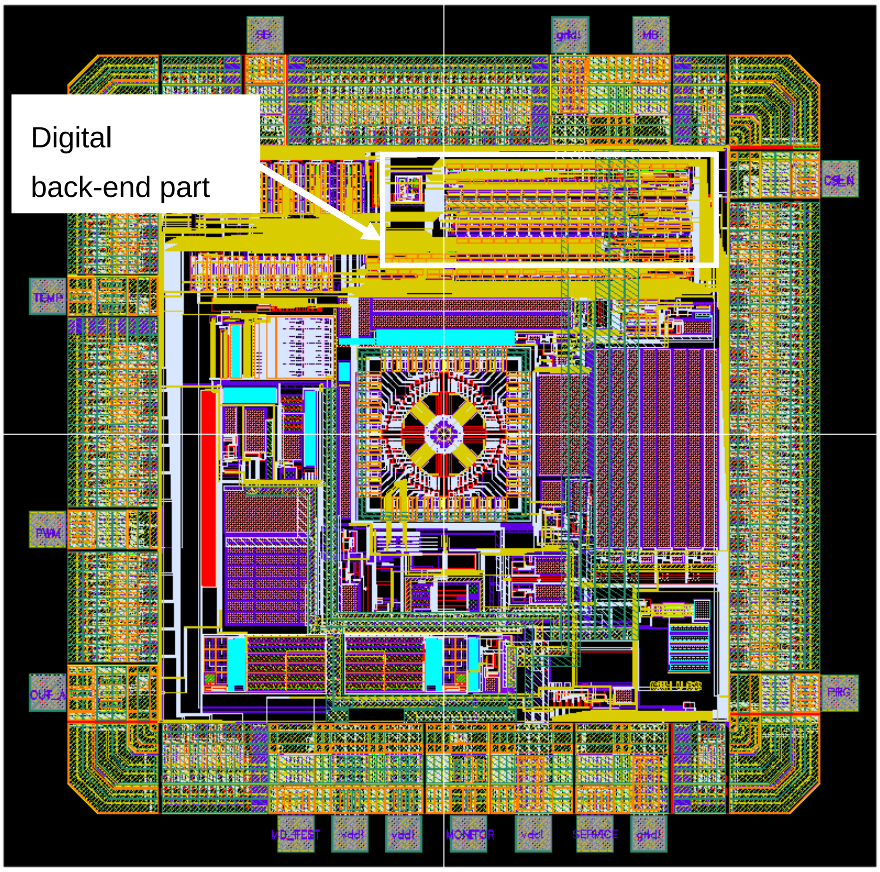


Figure 3: Layout of CAPS chip V6.9

5.5 UPDATED TEST BOARD DESIGN

In order to perform the CAPS V6.9 evaluation campaign and in particular to be able to perform temperature measurements in the temperature range between -40°C and +85°C, at ambient pressure, a new test board is being developed in the framework of the CAPS project phase IIIa. However due to the extent of this work both in terms of complexity and in term of delivery time, the new test board will be delivered in due time during the execution of the CAPS IIIb phase with no impact on the overall project schedule. For this reason, as part of the phase IIIa, only conceptual design, schematics and a preliminary test plan will be available.

5.5.1 High Level Block Diagram

The high level schematic of the updated test board is shown in Figure 4.

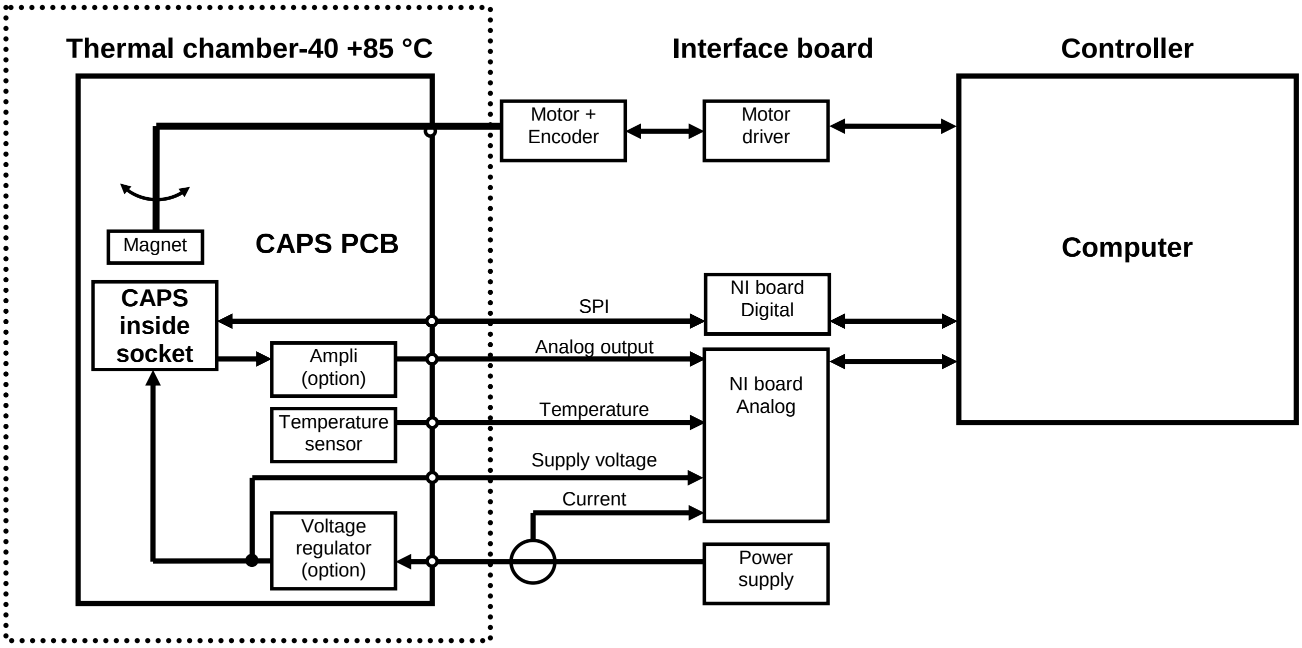


Figure 4 High level Block diagram of the updated test board

The final solution considered and evaluated for the updated test board is to have the motor and the encoder outside the thermal chamber, thus reducing the complexity of the components and the potential thermal drift on electromechanical parts.

5.5.2 Test board design

The retained solution is proposed by HCM is shown as a 3D CAD model in Figure 5.

The chip, PCB and magnet are in the thermal chamber, while all electronics and mechanics are outside the thermal chamber. The magnet will be rotated by the motor via a mechanical axis which will pass through the feed of the thermal chamber.

Details of the chip and assembly are shown in Figure 6.

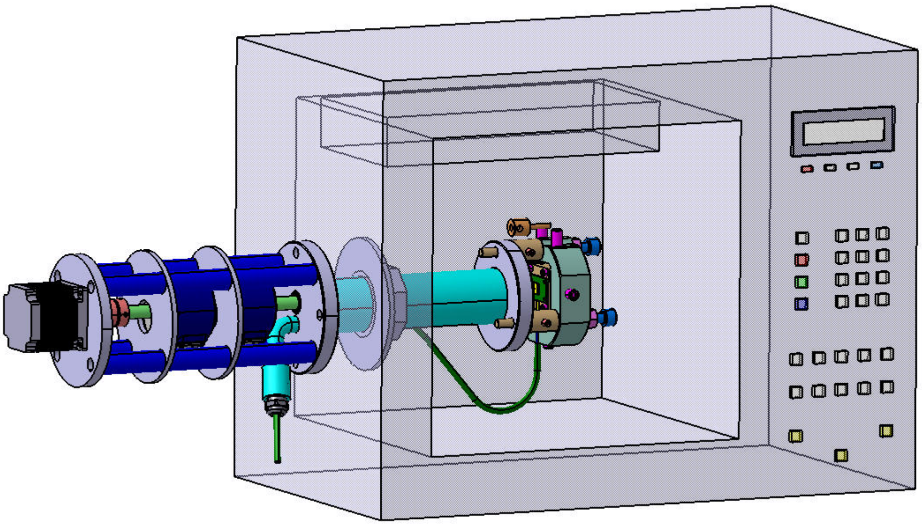


Figure 5 3D CAD Design of the updated test board

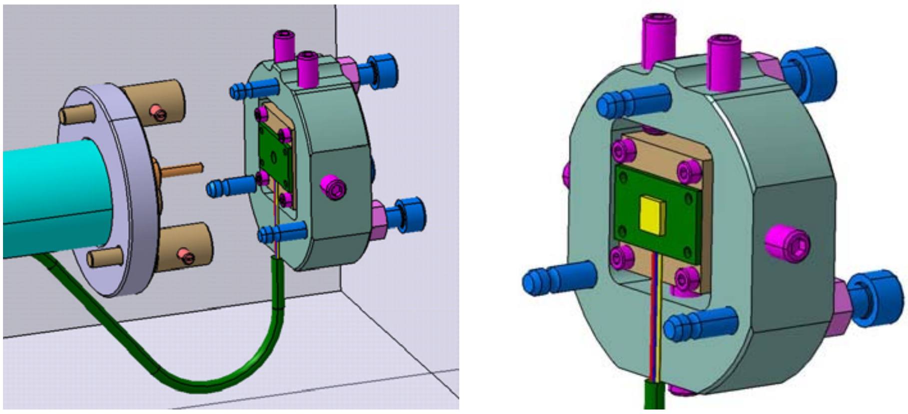


Figure 6 3D CAD Design of the updated test board detail of the chip position

Details on the test board electronic schematic, functionalities and programming are available in [RD7].

The design of the new test board being quite advanced at the time of edition of this report preliminary pictures of the assembly are shown in Figure 7.

Figure 7 Pictures of the mechanical assembly of the new test board

5.6 TESTING APPROACH

CAPS chips V6.9 have been fabricated and encapsulated. 33 chips were available for the pre-evaluation test campaign. Among these chips 7 have been kept unlidded for the usage in a SEE test.

The chips identified for these tests are shown in [RD8] as part of the encapsulation report.

The tests performed during the pre-evaluation campaign are shown in Table 1.

Test	**Number of samples**	**Equipment**
1) Functional test at room Temperature (Alter)	**24 samples**	**Present test board**
2) Measurements at high & low temp (-30ºC to +60ºC) (Alter)	**24 samples**	**Present test board**
3) Dynamic test at assembly level (-40°C to + 85°C, 10^{-5} mbar) (SENER)	**2 samples**	**SENER assembly**

4) TID test **Radiation performed by Alter. Test performed by Alter**	**3 samples**	**Chips only + socket**
5) Single event effect on unlidded chips SEE (Alter via subcontract)	**3 samples**	**Chips only + socket**
6) Burn in test (Alter)	**21 samples**	**Chips on sockets**
7) Post burn in Functional test at room temp. (Alter)	**21 samples**	**Present test board**

Table 1 – CAPS V6.9 pre-evaluation test list

Details on the different test procedures are provided in [RD7].

The new test board developed especially for the evaluation phase CAPS phase IIIb is described in more details in [RD7].

It is developed for working in the thermal chambers in Alter technologies and RUAG. The test plan of the delivered test board is shown in the following Table 2:

Test type	Parameters	Objective
Interface test	Dimensions	Verify the suitability of the test board in the thermal chambers in Alter and RUAG
Functional	Motor speed Electronics	Verify the functionality of the test board motor and define the motor speed lower and upper limits Verify the functionality of the electronic circuitry at room temperature
Thermal	Motor speed Electronics	Verify the stability of the test board mechanics and electronics in the different temperature conditions -40°C to +80°C
Calibration	Encoder reading	The calibration method is tested and validated. A calibration validity date is set as output of this test.

Table 2 – CAPS Evaluation test board test plan

6. OUTCOMES AND RESULTS

The final performances of the CAPS 6.9 and relative comparison to previous versions 6.7 and 6.8 are summarized here below:

Performance summary v6.7, v6.8 and v6.9

- **Summary**
  - Stable over temperature range -30°C to + 60°C (v6.7 and v6.8)
  - Stable over temperature range -40°C to + 85°C (v6.9)

Performances	**V6.7**	**V6.8**	**V6.9**
Digital output			
▪ Accuracy (without calibration):	2°	1.9°	2°
▪ Resolution (bit equivalent @ 3s):	9.3 bits	10 bits	10 bits TBC
Analog output			
▪ Accuracy (without calibration):	2.5°	2.2°	3°
▪ Resolution (bit equivalent @ 3s):	8.6 bits	9.4 bits	9.2 bits
Power Consumption (8mA under 5V)	40mW	40mW	40mW
Dynamic output refresh rate			
▪ Digital	1KHz	1KHz	1KHz
▪ Analog	1KHz	60Hz	60Hz

6.1 TEST RESULTS SUMMARY

All functional tests, as described in the test plan in [RD7] and reported in [RD8], have given good results with few exceptions that have required further investigation.

A summary of the main results and on the discussions and decisions taken over said exceptions is reported in the full final report [RD11].

The decision to validate the design of CAPS chips V6.9 was taken in October 2015 and approval for the fabrication of 1200 chips for project phase IIIb was given by ESA in the same occasion.

7. CONCLUSION

7.1 CONCLUSION AND RECOMMANDATIONS

In the frame of previous and current activities (GSTP, phase I and phase III), the feasibility of the project has been confirmed and verified through the manufacturing and testing of different samples. The CAPS sensor reached TRL-5.

In the framework of the present phase IIIa pre-evaluation, 40 samples were fabricated and tested to demonstrate the appropriateness for moving to the next phase of the project, phase IIIb evaluation phase.

The pre-evaluation test campaign has given the following results:

- The noise issue present in v6.8 is now solved in version v6.9 with the performed design modifications.
- The performances of the chip v6.9 are in line with the expectations, i.e. similar to those already demonstrated in the previous versions.
- The pre-eval test campaign overall has given positive results in all tests with the following recommendations:
  - The bonding pads are enlarged to 100x100μm^2
  - The statistics for the SEE test should be increased during phase IIIb test campaign
  - The soldering process of the cables on the pcb for the sensor assembly should be revised

Approval for the fabrication of 1200 chips with enlarged pads for the Evaluation Phase has been given by ESA in October 2015 and the development plan scheduled for the next IIIb phase is detailed in the full report [RD11].