Miniaturization of a Magnetometer based on Micro Technology

Activity Summary May 2013

1 Company Presentation

Lusospace, Lda.

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Lusospace was founded in 2002 and since then it has been increasingly involved in the space sector through numerous innovative and diverse programs. The AMR magnetometer being the first space hardware internally developed intended to fly in AEOLUS ESA satellite in 2007.
Along these years, extensive know-how in critical areas has been fostered and consolidated which together with a strong team-work culture has allowed Lusospace to acquire the necessary capabilities to successfully tackle ambitious and technologically challenging projects.
LusoSpace is a privately held company, covering the following main fields of activities:

- Attitude and Orbit Control System (AOCS)
- Laser systems and optoelectronics
- Electric Propulsion
- MEMS / MOEMS

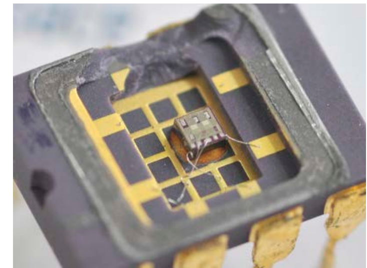
Previous activities in MEMS included the projects “Procedures for MEMS Qualification” and “Optical MEMS for Earth Observation”. Current projects include “Connectivity and Packaging of Systems-of-Microsystems” and “Validation and experimental verification of ESA MEMS qualification methodology”.
Previous and current activities in MEMS field provide important knowledge in the packaging and qualification of MEMS for space applications.
Lusospace vision is founded in two main cornerstones. The first is to the lead the space sector in the Portuguese market and the second is to develop and sell terrestrial applications which result from our space experience and its success.
Lusospace in this project is supported by the University of Minho, from Braga in Portugal.

2 Overview / Scope of Activity

This activity is part of the ESA General Support Technology Programme, phase 5 (GSTP-5). The overall objective the project is to prototype and extensively characterise a fully monolithic magnetometer based on MEMS technology. Being monolithic will allow easier, faster and cheaper space qualification via the ESCC systems.

The development of a MEMS magnetometer is a strategic activity for Lusospace. After a successful launch of an in-house developed and manufactured magnetometer, Lusospace has already successfully manufactured Magnetometers for several space missions. Being one of the leading magnetometer suppliers in Europe, the AOCS segment remains firmly in the company’s long term strategic outlook. Running in parallel, the company’s MEMS business area has shown strong growth with solid know-how in the MEMS testing and qualification fields.

In this context, primary achievements in this activity shall be:



- design and modelling of MEMS based magnetometer;
- processing and complete prototyping including packaging
- functional and performance testing, including ESCC evaluation

Required specification for the MEMS magnetometer:

- Dynamic Field Range: ± 64 µT
- Linearity: < 0.5 % (full scale)
- Alignment: better than ± 1°
- Power consumption: < 1 W
- Radiance Tolerance: 100 krad

Timescale

The overall project duration is planned to be 24 months starting from May 2nd, 2013.

3 Activity approach and Work Structure

The activity approach and work structure for the study "Miniaturization of a Magnetometer based on Micro Technology" are based on the ESA Statement of Work ref TECQCT/SoW12MAGN/NS-LM.
The work breakdown structure is divided into 4 major technical tasks and 1 management task. The first part of the activity shall be dedicated to the preparation and development of a monolithic MEMS magnetometer for space application and it consists of 3 distinct tasks. The second part shall be dedicated to the prototyping of the MEMS magnetometer.

Part 1: MEMS Magnetometer Development

Task 1: Magnetometer Pre-Development

Major objective of task 1 is to consolidate the system requirements. The survey of available ASICs and the foundry shall be selected for the volume manufacturing of the magnetometer Detail activities in this task are:

WP1100 – IP Management

IP portfolio will be analysed and the need for new IP will be identify. The IP survey should include the following domains: magnetometer; ASIC; MEMS manufacturing processes; monolithic integration and packaging. The result will be presented in Technical Note 1.1.

WP1200 – System Requirements Definition

The detailed list of requirements that the magnetometer shall satisfy shall be consolidated. The list should include functional and performance requirements, interface requirements and environmental requirements. The resulting list will be presented in Technical Note 1.2.

WP1300 – ASIC Survey & Foundry Selection

A survey of different ASIC foundries for the manufacturing of the final device will be performed. Selection of the foundry will respect the following criteria: experience, availability of ASIC designs, stability of the process, cost, time for production, minimum quantity. The foundry survey and selection will be presented in Technical Note 1.3.
Task 1 will be completed by collecting the information from TN1.1, TN1.2 and TN1.3 into Technical Note 1 and present it in a System Requirements Review.

Task 2: Magnetometer Concept Development

Aim of Task 2 is to prepare the preliminary design of the sensor as well and the preliminary manufacturing plan. At that stage, the contractor shall also set-up a risk analysis plan in the form of a FMEA.

WP2100 – Preliminary Design and Process Analysis

The preliminary design of the MEMS magnetometer and of the necessary lithographic masks to fabricate it will be prepared. The preliminary process plan associated with the MEMS design will be prepared, including a complete process flow of the fabrication sequence.
The different process steps and material involved in the fabrication of the device will be described in detail. The interaction between the different materials will be analysed to highlight possible areas of

concern. This analysis shall at least look at the chemical compatibility between process chemicals and materials used during the fabrication; stress creation and/or concentration due to design constrains, processes or material interfaces. The result of the work performed in this WP will be presented in a Technical Note 2.1.

WP2200 – Process Optimization

The work performed in WP2100 will be used to find the areas of improvement and, if necessary, optimize the process plan. The contractor shall investigate the pro/cons of the different possible fabrication routes and determine the optimal solution in terms of: process simplicity; process robustness; cost, and time of manufacturing.

The optimized process flow, including the final process workflow will be presented in a Technical Note 2.2.

WP2300 – Risk Analysis

A risk analysis will be prepared based on the design and manufacturing plan proposed by the contractor in the previous work packages. The risk analysis shall be performed in the form of a FMEA.

The first stage is the preparation the FMEA template and the submission of the rating plan to ESA Technical Officer for approval. After receiving the approval, the contractor shall complete the FMEA and rate the different risk following the approved ratings.

A mitigation plan for the top risks should be proposed. The top risks shall be defined based on a FMEA score decided after discussion and approval of the FMEA ratings by ESA Technical Officer.

The identified top risks and their mitigation plans will be described in detail in Technical Note 2.3. The full FMEA table shall be attached to this TN.

WP2400 – Preliminary Manufacturing Plan

A preliminary manufacturing plan of the MEMS Magnetometer will be prepared. This manufacturing plan shall reflect the risks highlighted in the previous WP and shall formulate a realistic business and development plan that takes into account: the development risks identified in WP2300; the cost and time for the production transfer to a foundry, and the cost and time require for the device validation.

The preliminary manufacturing plan will be presented in a Technical Note 2.4.

In Technical Note TN2 will be presented the regrouped results of the work performed within this task (TN 2.1, TN 2.2, TN 2.3 and TN 2.4). TN2 will be presented in a Preliminary Design Review (PDR).

Task 3: Magnetometer Design & Modelling

The objective of Task 3 is refining the sensor design and model. Simulation of the device will predict the performance, non-linearity, crosstalk, and other output specifications of the sensor. Design test structures for material, process and properties evaluation shall also be performed.

WP3100 – Models and Manufacturing Process Variation Analysis

Based on the device design and fabrication sequence will be created analytical and/or numerical device design models to allow the accurate prediction of the physical behaviour of the MEMS.

The source and magnitude of variation in the MEMS fabrications process will be predicted. For each source of variation identified, shall be identified the implication of the variation on the remaining fabrication step and on the overall performance of the magnetometer.

Technical Note 3.1 will be prepared, including a full description of the device models and the result from the manufacturing process variation analysis

WP3200 – Device Design Desensitization and Material Analysis

Using the manufacturing process variation analysis performed in the previous WP, modification will be performed in the device preliminary design and process sequence in order to desensitize it from the process variation. Verification that each modification does not compromise on the overall performance of the MEMS device and does not impact the sensitivity to process variation in other parts of the fabrication sequence will be required.

A material analysis will be performed in order to predict the material properties based on the manufacturing sequence. The material analysis shall cover all aspects of the device and include at least: the complete list of materials; the intrinsic material properties (electrical, physical, chemical) including for thin films; the resistance to chemicals of the materials based on the fabrication sequence; the stress build-up during processing; and the materials in contact including possible interface effects.

A Technical Note 3.2 will be prepared regrouping the result form de the device design desensitization and from the material analysis

WP3300 – ASIC Simulations

First it is required to ensure that the ASIC fulfil the requirements defined in WP1200. Based on the ASIC properties and on the MEMS fabrications sequence, a series of simulations will be performed: manufacturing process simulation, device simulation, system simulation and package simulation.

Technical Note 3.3 will be prepared, describing, in detail, the input and results of the different simulation performed during this WP, the simulation scripts shall be attached as annexes to the TN.

WP 3400 – Test Structures Design and Optimization

The design of test structures that will be added on the mask layout in complement of the standard Process Control Monitors (PCMs) will be prepared. Those test structures shall be dedicated for testing material properties, process characterization and functional performance characterization. Each test structure will isolate the desired property/function to be characterized. The test structures shall be place in cluster in 5 representative area of the wafer: centre, top, bottom, left and right.
Technical Note 3.4 will be prepared, describing each test structures and their intended use. This TN shall also include the expected result from the test structures.

A Technical Note 3 will be prepared, regrouping the results of the work performed within this task (TN3.1 to TN3.4) and it will be presented during a Critical Design Review (CDR).

Part 2: MEMS Magnetometer Fabrication

<u>Task 4: Prototype Fabrication</u>

The objective, in Task 4, is to develop the manufacturing process and fabricate a limited number of prototypes of the packaged MEMS magnetometer for extensive characterisation.

WP 4100 – Process Steps Validation

The short-loop fabrication process defined in WP3300 will be performed in order to validate the different process steps of the manufacturing plan.
If problem areas are identified during this process step validation short-loops, ESA Technical Officer shall immediately be informed and quickly identified and developed solutions for the problem. Those solutions shall again be validated by means of new short-loops and also analysed the influence of the process/design modifications to the rest of the manufacturing plan.
Technical Note 4.1 shall be prepared presenting the result from the short-loop tests and explain in detail any modification brought to the design and/or manufacturing plan as a result of the process step validation experiments.

WP 4200 – Prototype Manufacturing and Process Monitoring

Manufacturing of a first lot of devices according to the manufacturing process plan consolidated with the results from the short-loop processing and using the foundry selected in WP1300.
A full inspection of the dies upon receipt will be performed and ESA Technical Officer will be notified for any irregularities.
All dies received and all test structures shall be tested in order to monitor the fabrication process and asses the manufacturing yield.
Then a minimum of 15 dies shall be packaged for extensive functional testing, constructional analysis and early radiation testing. The assembly and packaging techniques shall be identical as those intended for the future FM devices. Functional test on all 15 packaged MEMS magnetometers shall be performed to verify that they comply with the requirements set-up in WP1200.
A minimum of 2 packaged MEMS devices shall then be delivered at ESA for its own assessment of the part.
The early radiation testing shall include a minimum of 4 samples for TID (total Dose Testing and 4 samples for SEE (Single Event effect Testing). ESA will provide the facilities depending on their availability at the time of testing. Finally, Technical Note 4.2 shall be written describing the outcome of the manufacturing process, the manufacturing yield, the packaging process and the functional testing results.

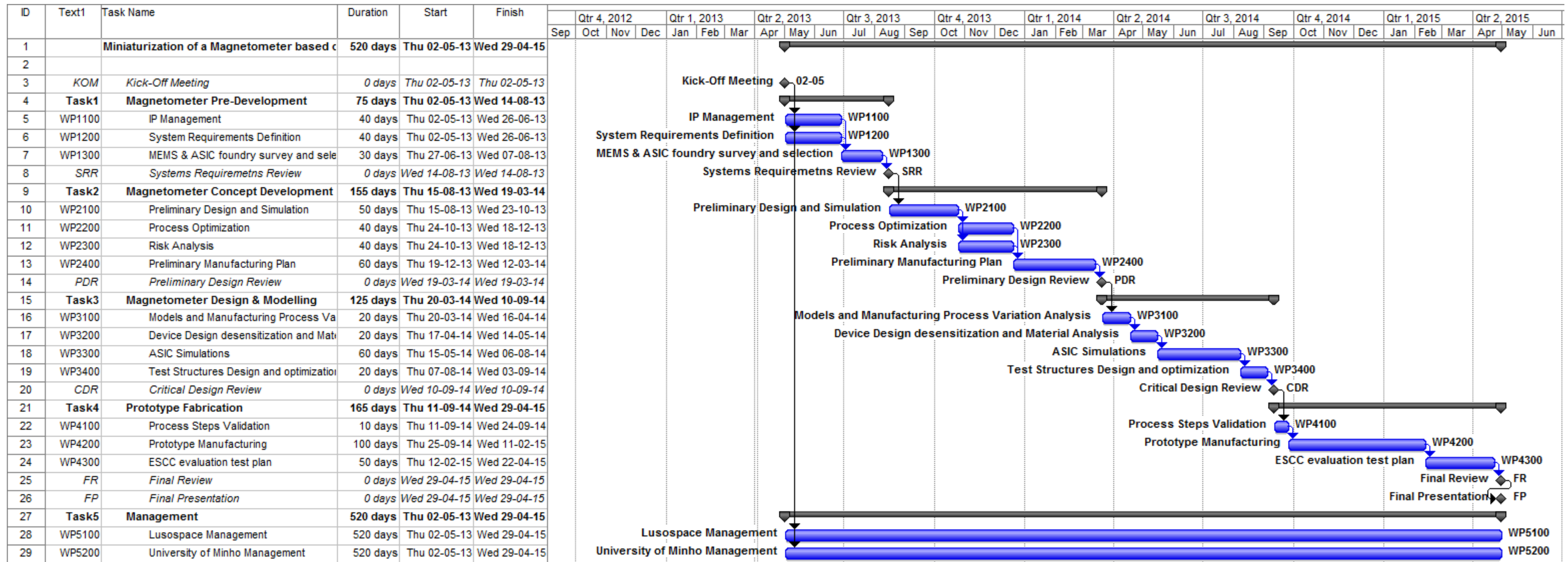
WP 4300 – ESCC evaluation test plan

Here an evaluation for the package magnetometers following the ESCC 22600 specifications shall be prepared. This space compatibility evaluation test plan shall consist of different test group including: mechanical environment; thermal environment; EMC test; life test, radiation test, and construction analysis.
The space compatibility evaluation test plan shall describe at least:

- The test method and procedure, test sequence, test conditions, when relevant in reference to MIL-STD and ESCC documents;
- The pass-fail criteria;
- The initial inspection and performance tests, the intermediate performance tests and the final performance tests;
- The foreseen test facilities and test equipment;
- The number of test samples.

A Technical Note 4.3 that shall contain the evaluation test plan shall be prepared.

A Technical Note 4 shall be prepared, regrouping the results of the work performed within this task (TN4.1, TN4.2 and TN4.3) and presented during a Final Review (FR). The packaged dies (minimum 2) shall also be given to ESA once they have been fully characterised in the frame of WP4200.



ID	Text1	Task Name	Duration	Start	Finish
1		**Miniaturization of a Magnetometer based c**	**520 days**	**Thu 02-05-13**	**Wed 29-04-15**
2					
3	*KOM*	*Kick-Off Meeting*	*0 days*	*Thu 02-05-13*	*Thu 02-05-13*
4	**Task1**	**Magnetometer Pre-Development**	**75 days**	**Thu 02-05-13**	**Wed 14-08-13**
5	WP1100	IP Management	40 days	Thu 02-05-13	Wed 26-06-13
6	WP1200	System Requirements Definition	40 days	Thu 02-05-13	Wed 26-06-13
7	WP1300	MEMS & ASIC foundry survey and sele	30 days	Thu 27-06-13	Wed 07-08-13
8	*SRR*	*Systems Requiremetns Review*	*0 days*	*Wed 14-08-13*	*Wed 14-08-13*
9	**Task2**	**Magnetometer Concept Development**	**155 days**	**Thu 15-08-13**	**Wed 19-03-14**
10	WP2100	Preliminary Design and Simulation	50 days	Thu 15-08-13	Wed 23-10-13
11	WP2200	Process Optimization	40 days	Thu 24-10-13	Wed 18-12-13
12	WP2300	Risk Analysis	40 days	Thu 24-10-13	Wed 18-12-13
13	WP2400	Preliminary Manufacturing Plan	60 days	Thu 19-12-13	Wed 12-03-14
14	*PDR*	*Preliminary Design Review*	*0 days*	*Wed 19-03-14*	*Wed 19-03-14*
15	**Task3**	**Magnetometer Design & Modelling**	**125 days**	**Thu 20-03-14**	**Wed 10-09-14**
16	WP3100	Models and Manufacturing Process Va	20 days	Thu 20-03-14	Wed 16-04-14
17	WP3200	Device Design desensitization and Mat	20 days	Thu 17-04-14	Wed 14-05-14
18	WP3300	ASIC Simulations	60 days	Thu 15-05-14	Wed 06-08-14
19	WP3400	Test Structures Design and optimizatio	20 days	Thu 07-08-14	Wed 03-09-14
20	*CDR*	*Critical Design Review*	*0 days*	*Wed 10-09-14*	*Wed 10-09-14*
21	**Task4**	**Prototype Fabrication**	**165 days**	**Thu 11-09-14**	**Wed 29-04-15**
22	WP4100	Process Steps Validation	10 days	Thu 11-09-14	Wed 24-09-14
23	WP4200	Prototype Manufacturing	100 days	Thu 25-09-14	Wed 11-02-15
24	WP4300	ESCC evaluation test plan	50 days	Thu 12-02-15	Wed 22-04-15
25	*FR*	*Final Review*	*0 days*	*Wed 29-04-15*	*Wed 29-04-15*
26	*FP*	*Final Presentation*	*0 days*	*Wed 29-04-15*	*Wed 29-04-15*
27	**Task5**	**Management**	**520 days**	**Thu 02-05-13**	**Wed 29-04-15**
28	WP5100	Lusospace Management	520 days	Thu 02-05-13	Wed 29-04-15
29	WP5200	University of Minho Management	520 days	Thu 02-05-13	Wed 29-04-15