LOW COST LOW RESOLUTION POSITION SENSOR

ESA Contract 400012128512/19/NL/MG

Space Mechanisms Final Presentation Day

13 April 2023

Outline o the presentation

1. Review of project main goals and requirements

2. Final sensor selection and description.

3. Review of test campaign.

4. Analysis of results.

5. Conclusions.

1. Review of project main goal and requirements.

Main goal: design, manufacture and test a breadboard model (BBM) of a position sensor targeting low cost, low accuracy (8 to 10 bits) and high reliability.

- Establish a set of requirements based on market survey.

- Identify the most suitable solution to achieve the requirements established.

- Design a low cost, low resolution position sensor.

- Manufacture a breadboard model of the position sensor (TRL4).

- Perform functional testing of breadboard position sensor in laboratory conditions.

- Analysis of results.

1. Review of project main goal and requirements.

Market survey (ALTER):

- A market survey involved 25 European space industries

Parameter					
Power Consumption (mW)	200	350	1000	1000	No data
Measurement range	360º	360º	360º	360º	360/180/90º
Measurement accuracy	±0.3º	±0.2 – 0.6º	±0.01º	±0.01º	0.3 to 0.02º
Resolution	8-10 bits	10 bits	16 bits	16 bits	8-13 bits

Summary of comparative between several customers

1. Review of project main goal and requirements.

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LRPS main requirements

	Functional Requirements
LRPS_100	Measurement type: Absolute. Common requirement within the Space industry
LRPS_110	Measurement range: 360º. Measurement of one full revolution.
LRPS_120	Dead zones: None. Improved function w.r.t. potentiometers.
LRPS_130	Nominal/maximum speed steady: 30rpm. Use for high speed applications.
LRPS_140	Measurement overall accuracy in CW & CCW directions: 0.35º (10bits), 0,7º (9 bits) and 1.4º (8 bits).

	Physical properties and interfaces
LRPS_300	Mass <150g. We propose this weight as a maximum target
LRPS_310	Volume < 100mm in diameter and 15mm width
LRPS_320	Shaft attachment <50mm. Market demand to attend up to 50mm diameter shafts.

	Thermal and envioremen‌t
LRPS_500	Operation temperature (Qualification= -50ºC to + 100ºC) . High & low temperature measurements on prototype in test campaign.

	Lifetime
LRPS_800	Unit Cost (Excluding non-recurrent cost) < 5,000€. Identified market demand

1. Review of project main goal and requirements.

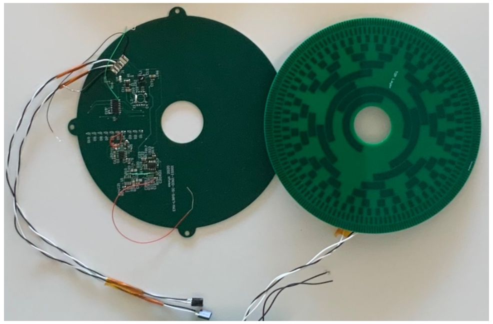
Main drives:

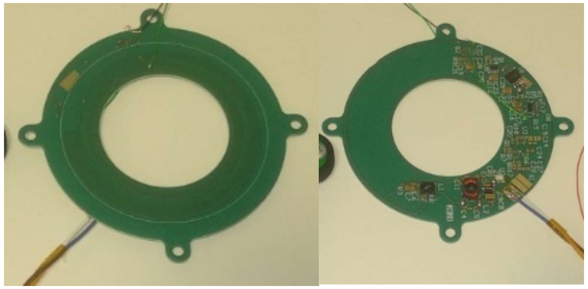
- Reduce cost implies no μP or FPGA
- Analog output preferred (direct potentiomenter sustitution).
- Size and weight may depend on the application (but similar to potentiometers).

2. Final sensor selection and description.

Several TRL2 technologies were tested:

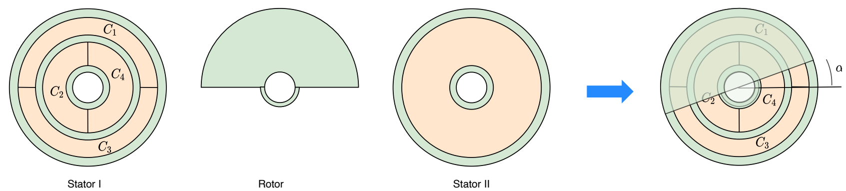
Technology	Ref. of Stator	Ref. of Rotor	ISS	Output	Description
Capacitive	0361	0363	02	Digital	The rotor couples the electrodes in the stator to generate a digital output. Digital circuit is used to generate the digital word.
Inductive	0362	0364	01	Digital	The rotor avoids any coupling in the transformer located in the stator, so the digital pulse is not transmitted by the transformer. Digital circuit is used to generate the digital word.
Capacitive	0366	0367	01	Digital	The capacitive coupling is measured by the device AD7747 and the measurement is transmitted by I2C.
Capacitive	0369	3610	04	Analog	In this option, the rotor couples to electrodes in the stator. One of these electrodes has a shape that depending in the angular position.

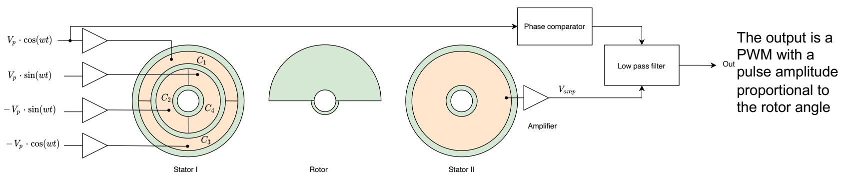




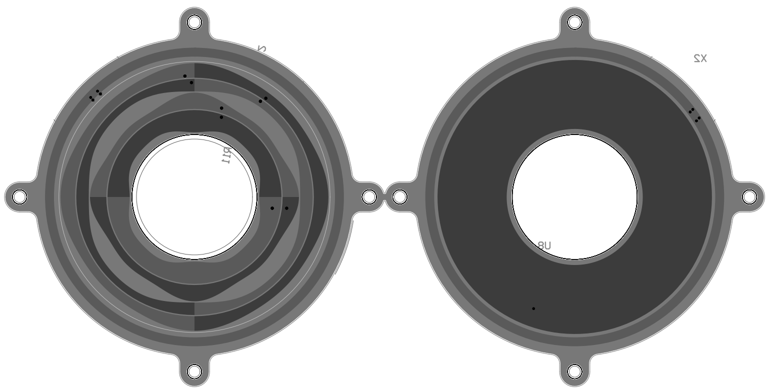
2. Final sensor selection and description.

- Final concept for LRPS: mechanical configuration





The output is a PWM with a pulse amplitude proportional to the rotor angle



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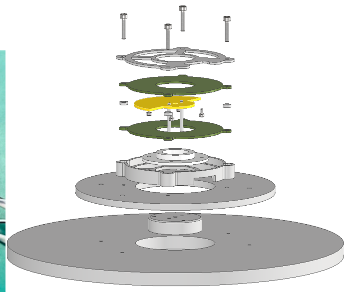
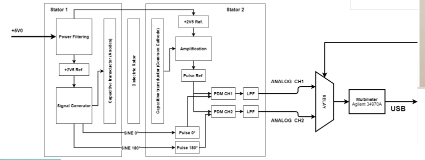
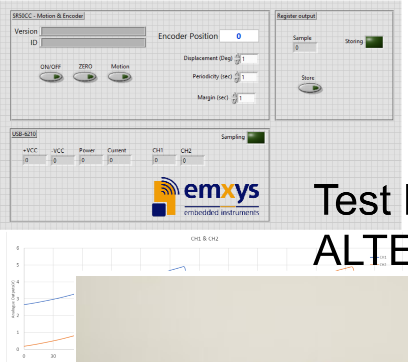
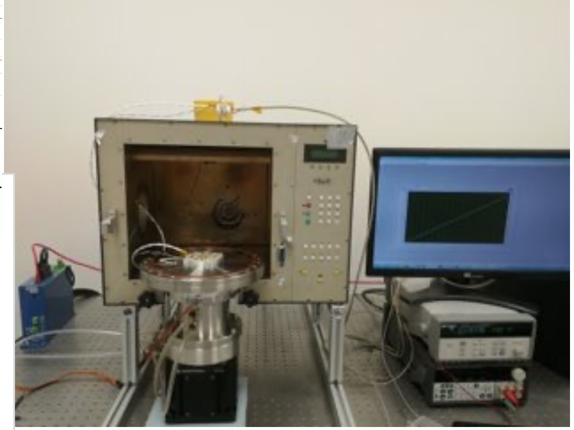
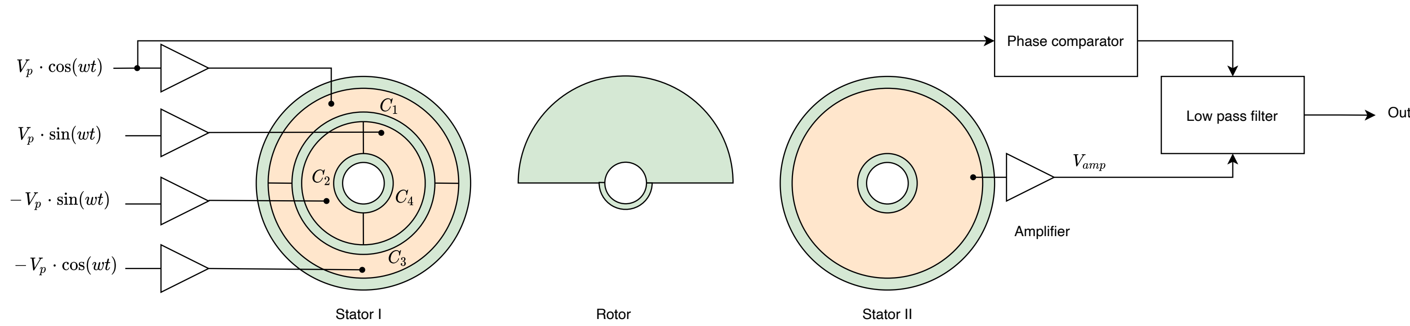








2. Final sensor selection and description.



The output is a PWM with a pulse amplitude proportional to the rotor angle

Very simple electronics: all space qualified counterparts with a ROM Price of 4000€ aprox. (for small number of units).

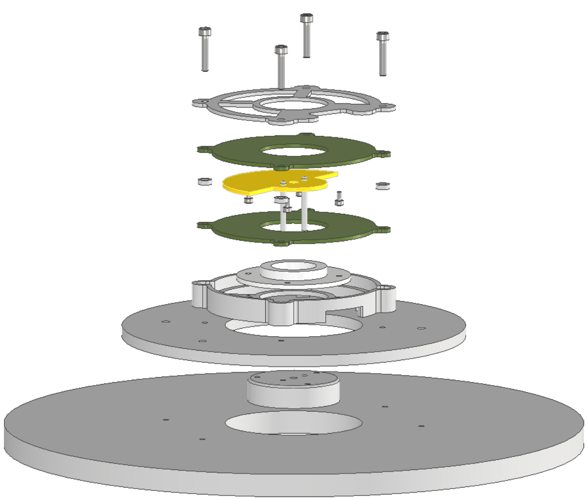
- ✓ 2 x 4-opam ICs + 4 logic gates + 1 flip-flop (1 output).
- ✓ + 1 x 4-opam + 4 logic gates + 1 flip-flop (2 output partial redundancy).

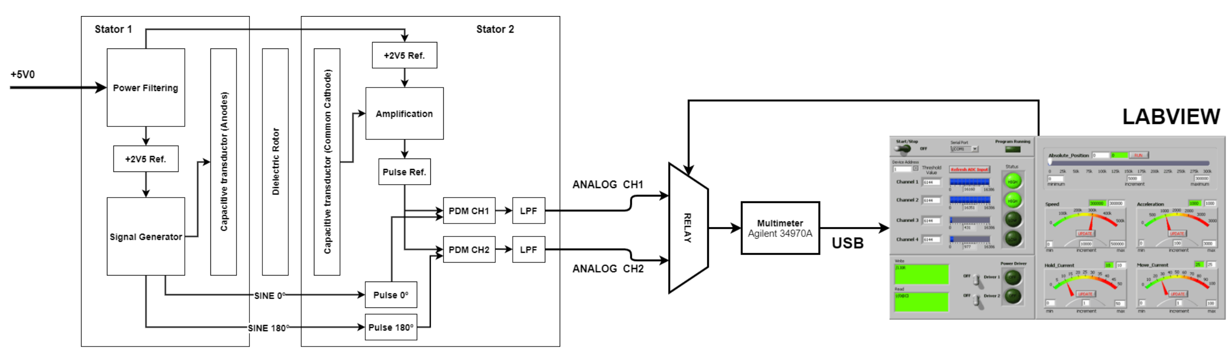
2. Final sensor selection and description.

Test bench and software

Sensor	LRPS Breadboard		
Signal	Input	Output	Voltage
Vcc	X		4.5V to 5.5V
GND	--	--	0V
Chassis	--	--	0V
Output 1	--	X	0V to 5.5V
Output 2	--	X	0V to 5.5V

Electrical interface for proposed design.





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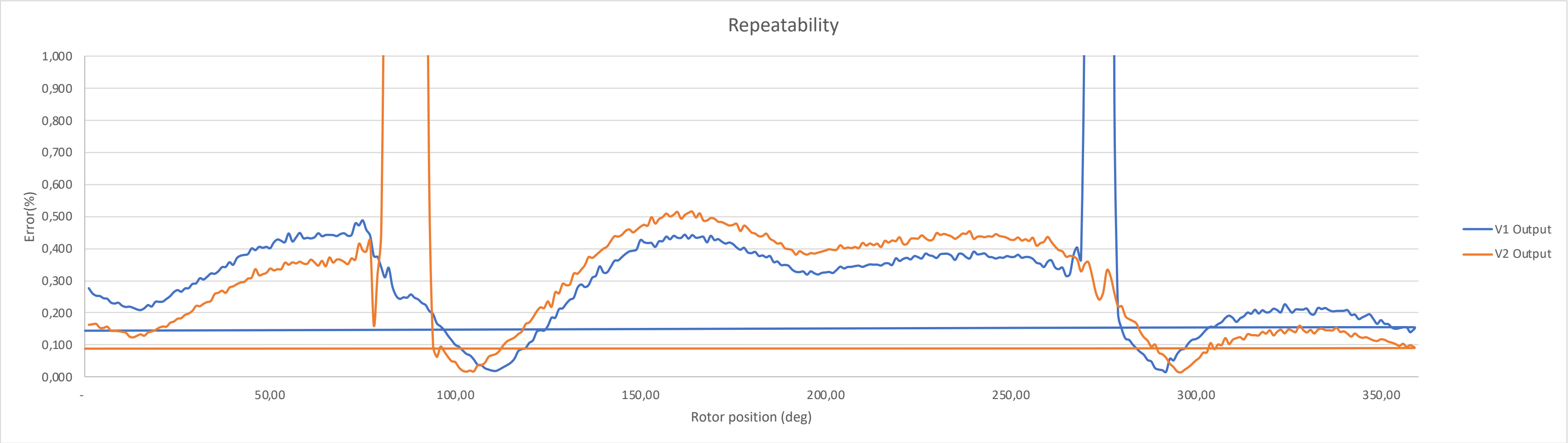
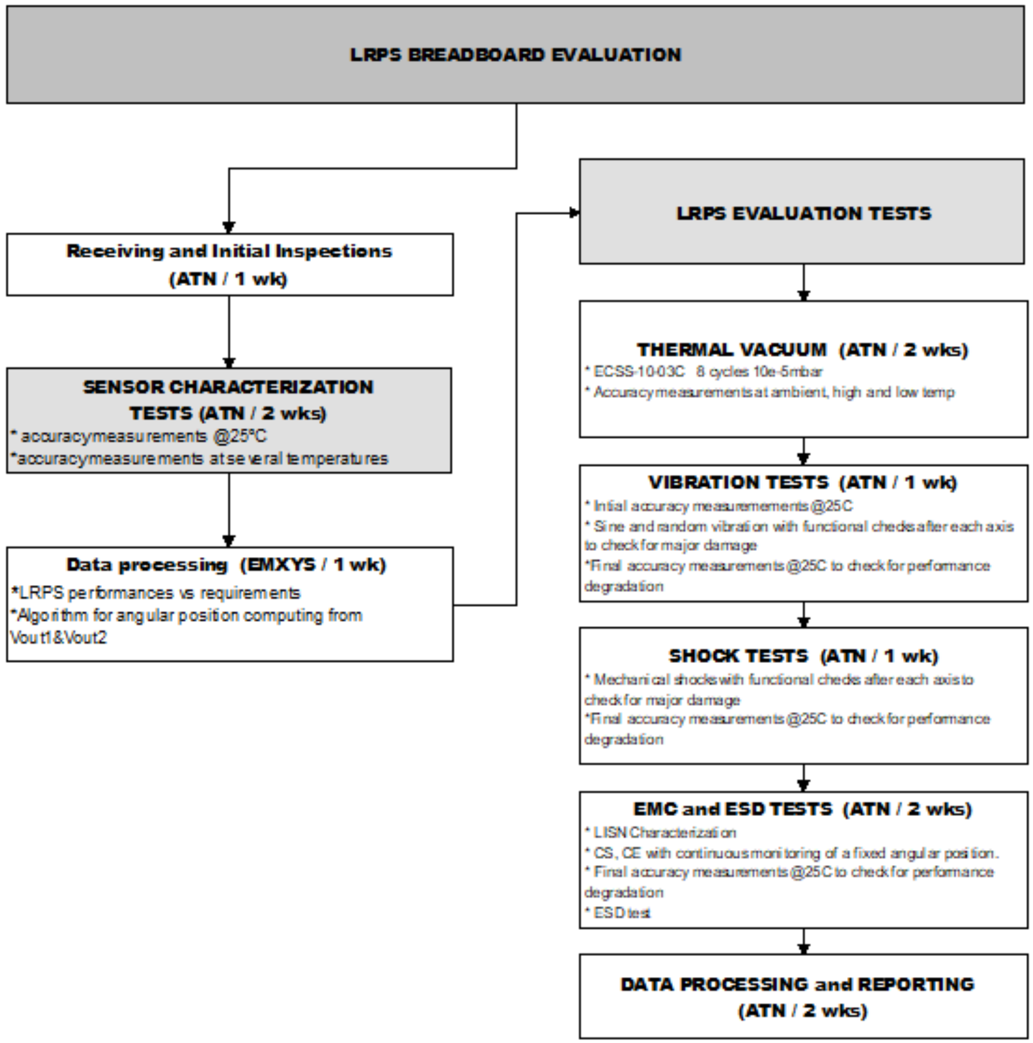


8-bit = 0.4%

3. Review of test campaign.

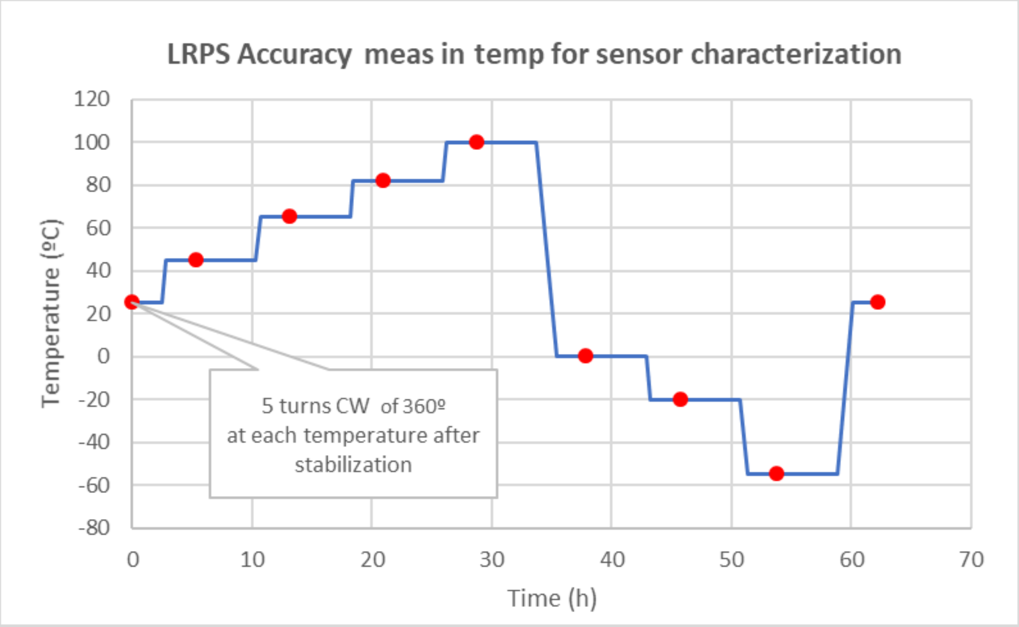
Test flow and schedule at ALTER

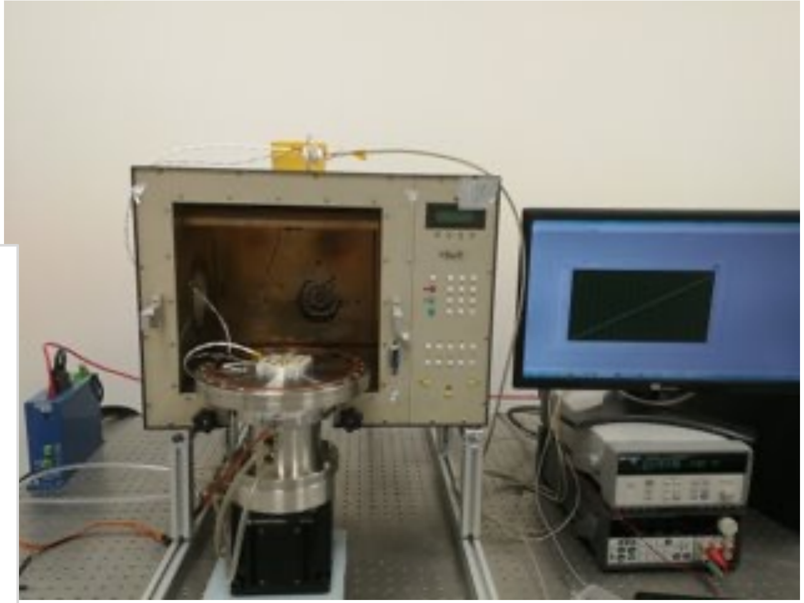


SENSOR Characterization

* **At 25ºC**, 5 measures CW and 5 measures CCW (Step 1º, range 360º, wait at each step 5 sec)

* **At several temperatures** in functional range, 5 measures CW (Step 1º, range 360º, wait at each step 5 sec)





Outputs:

*algorithm for angular position calculus

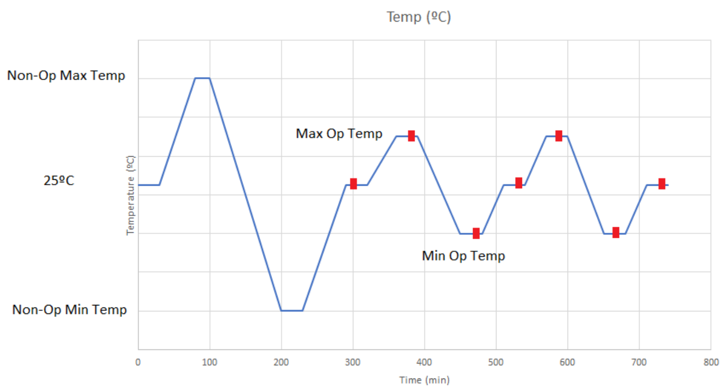
*LRPS performances table to be checked durig evaluation campaign

3. Review of test campaign.

LRPS evaluation tests

Thermal Vacuum

*using accuracy measurements test bench
*2 measures CW (Step 1º, range 360º, wait at each step 5 sec) at high and low temperatures



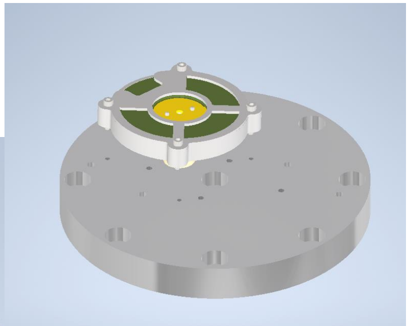
EMC and ESD

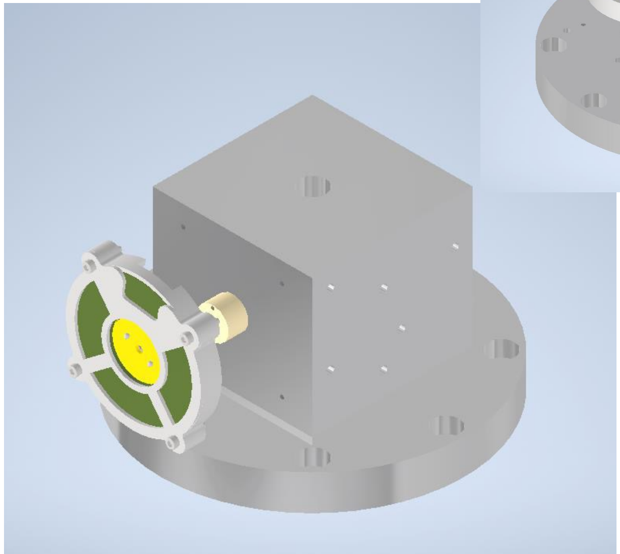
*CS and CE
* sensor fixed position monitoring
* use the LISN manufactured by EMXYS
* accuracy measurements after tests

Mechanical tests

*stator and rotor in a fixed position
*reduced functional tests after each axis test for major damage check
*accuracy measurements after tests

Cube F1=5183.76 Hz
Plate F1=10629.61 Hz





3. Review of test campaign.

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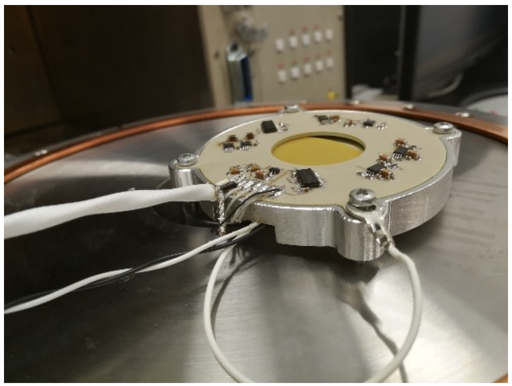
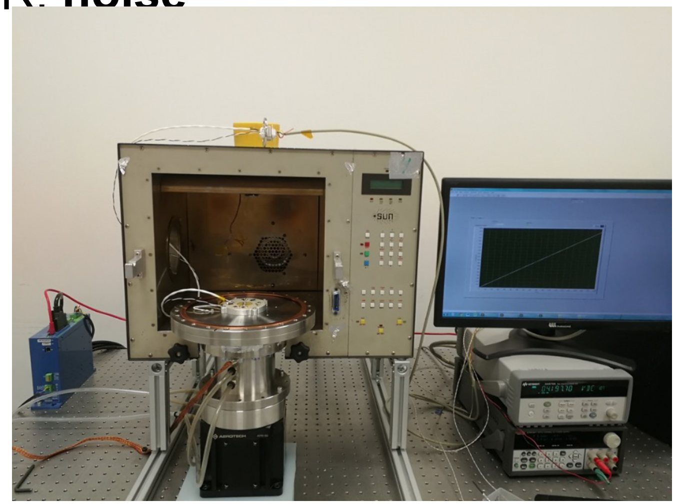
Instrument characterisation at ALTER: **noise**





Noise level for different positions.

Position (Deg)	V1			V2		
	Mean Value	Absolute noise range	Standard deviation	Mean Value	Absolute noise range	Standard deviation
0º	1.266V	2.9mV	0.04%	3.801V	2.8mV	0.04%
45º	1.806V	3mV	0.05%	4.341V	2.5mV	0.001%
90º	2.4659 V	1.2mV	0.018%	2.7802V	217.9mV	**3.845%**
135º	2.987V	4.2mV	0.07%	0.5469V	4.8mV	0.07%
180º	3.645V	1.8mV	0.03%	1.193V	1.9mV	0.04%
225º	4.198V	2mV	0.04%	1.745V	3mV	0.04%
270º	4.76V	189mV	**2.08%**	2.471V	5mV	0.05%
315º	0.652V	2mV	0.03%	3.186V	2mV	0.03%
360º	1.267V	5mV	0.04%	3.801V	4mV	0.04%

Noise figure is 5 times less the 8-bit resolution

3. Review of test campaign.

Temperature	Direction of rotation	Error Max.	Reference
25ºC	CW	<0.2º	REF0
25ºC	CCW	<0.7º	REF0
45ºC	CW	<7º	REF0
45ºC	CW	<2º	Temp. Ref.
65ºC	CW	<8º	REF0
65ºC	CW	<3.5º	Temp. Ref.
85ºC	CW	<8º	REF0
85ºC	CW	<4º	Temp. Ref.
0ºC	CW	<12º	REF0
0ºC	CW	<6º	Temp. Ref.
-10ºC	CW	<13º	REF0
-10ºC	CW	<3º	Temp. Ref.

Summary of maximum error in thermal characterization.

REF0 = 1st turn at 25ºC
Temp. Ref. = 1st turn at refered temperature

✓ TVAC and mechanical vibration did not alter the sensor measurement.

4. Analysis of results.

- **8-bit accuracy** is obtained at laboratory conditions.

- Improvements (mechanical and electronics) needed to increase TRL:

  - **Close the mechanical interface** and present the sensor as an equivalent mechanical substitution to potentiometers, with a mechanical (cylindrical) body and a rotating axis.

  - Improve the electronics to deliver **one analog outpu**t similar to potentiometers and minimize the “**death zone” to less than 5 degrees**.

  - **Realize an electrical interface** similar to potentiometers (one reference, +5VDC supply and output measurement between the reference and the supply).

  - **Improve the pattern of the stators** to minimize the error and a minimum of 10-bit over all the temperature range.

5. Conclusions.

- A **promising technology** that delivers space angular measurements at competitive prize for space applications has been identified.

- This technology is not feasible for industrial or automotive applications that are microprocessor based.

- After first **test in temperature** the accuracy of the sensor has been compromised due to mechanical issues. The complete range was not reached due to some parts that were out of range. Requirements affected:

  - LRPS_140 Accuracy 10-bit to 8-bit at all temperature range
  - LRPS_500 Temperature range

- The **Road Map**.

  - The sensor presents a good noise response with a very low power consumption.
  - The performance is quite repetitive at each temperature point.
  - Mechanical solution shall be improved to minimize the effect of the temperature on the resolution and easy integration.

THANKS!!!

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