HIGH ACCURACY IMAGE STABILISATION BREAD-BOARDING FINAL PRESENTATION

16/01/2023

Date : 16/01/2023
Ref : ISABELA FP
Ref Modele : 83230347-DOC-TAS-FR-006

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5 Conclusions

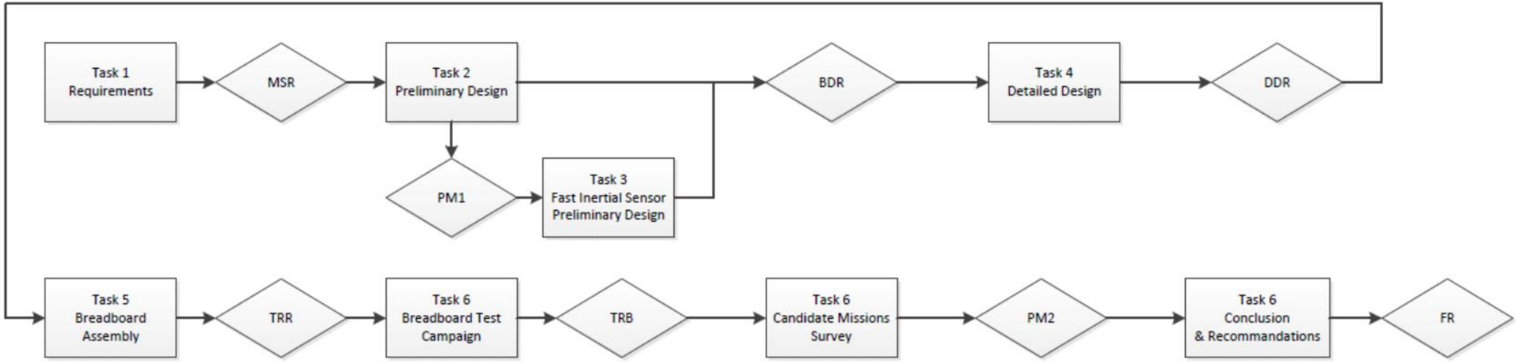
STUDY OBJECTIVES AND WORK LOGIC

MAIN OBJECTIVES

- Design, develop, manufacture a breadboard, and test a line of sight stabilization system suitable for hosted payload cases.
- Determining the achievable performances from results extrapolation.
- Define a preliminary concept of a high frequency angular rate sensor.

MAIN TASKS

- Mission requirement analysis
- LOS stabilization system design
- High frequency inertial sensor and fast steering mirror design
- Breadboard assembly and test campaign
- Candidate mission survey and conclusions



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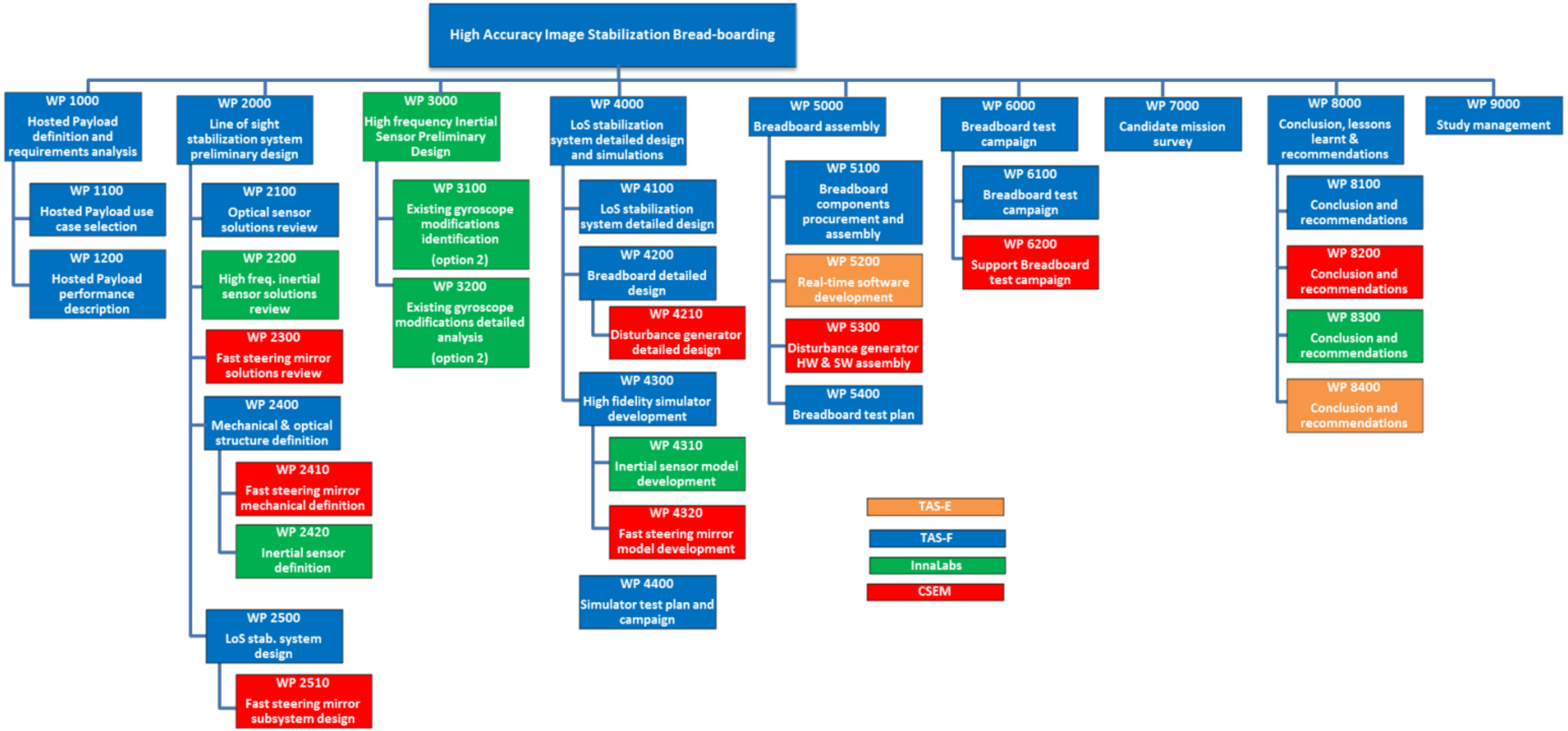
WORK BREAKDOWN STRUCTURE



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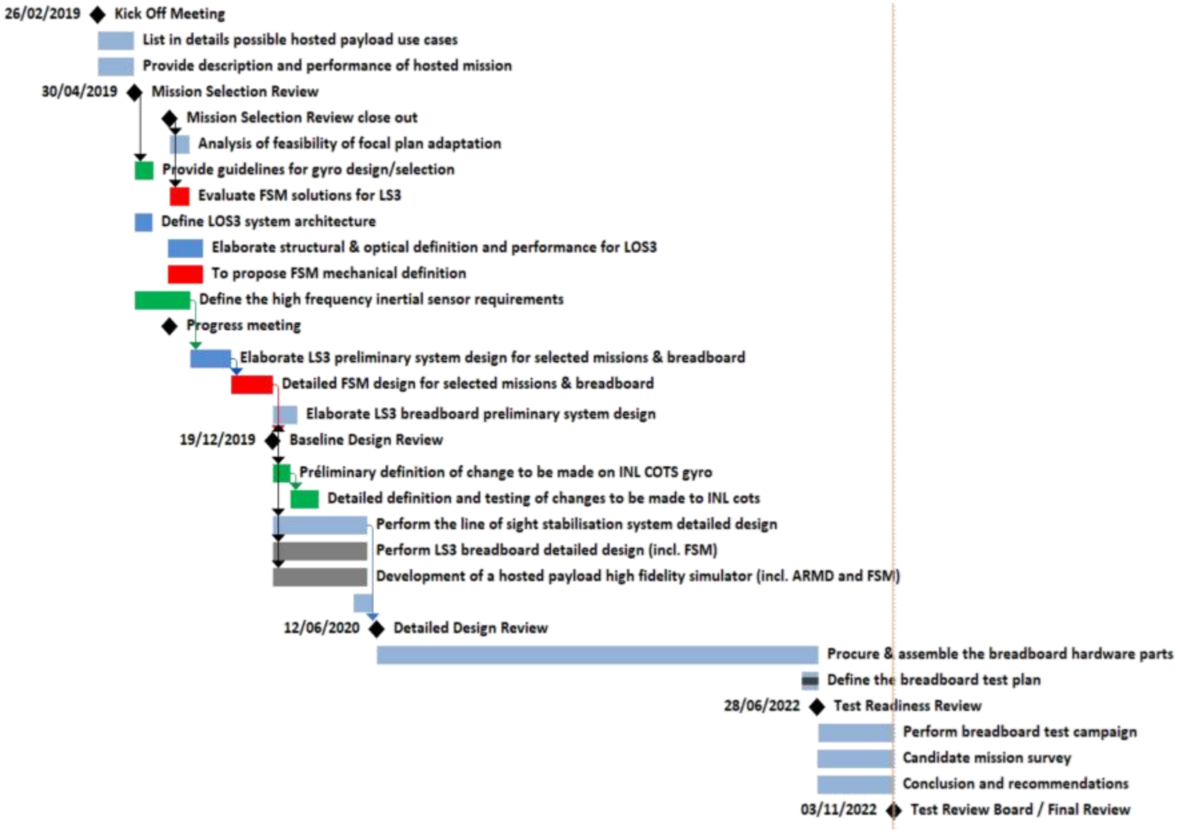
1. PLANNING



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2. HOSTED PAYLOAD MISSION SURVEY AND REQUIREMENT ANALYSIS

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2. HOSTED PAYLOAD MISSION SURVEY AND REQUIREMENT ANALYSIS

REQUIREMENT ANALYSIS

HOSTED PAYLOAD DEFINITION

- Payloads integrated in a platform that is not designed especially for it.
  - A platform with another primary payload performing a different missions
  - A standardized with low pointing performance not compliant alone to the payload requirements.

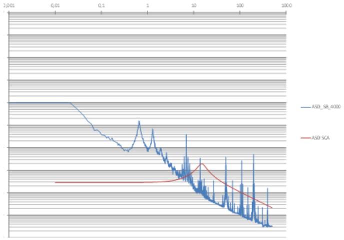
MAIN ACTIVITIES

- Assessment of different mission candidates and requirement analysis
- Development of a tool to compare the performance with and without LOS stabilization
- Definition of requirement according to three main needs:
  - Navigation => APE/AKE
  - Registration => PDE
  - Integration => RPE
- Computation of expected ASD from parameter assessments

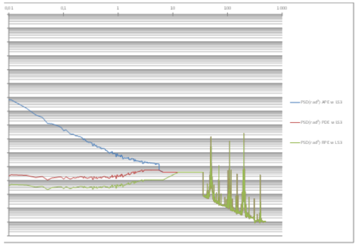
Platform and payload parameters

Satellite class		SB_4000
Mass	Kg	2000
Satellite f0	Hz	21
Acquisition principle		IFS2
Navigation factor : n		100
Registration factor : p		10
Integration factor : q		10
Instrument sizing		GEO IR M SI
Orbit		GEO
Altitude	m	3,60E+07
Scene scan strategy		
SCA		y
Scan encoder number of bits		28
Scan dynamic		6,28
Shorter scene acquisition time	s	0,2
Agility factor		0,050
Stabilization time	s	0,009
Actuation Control Loop cut-off frequency	Hz	15,00
Actuation Control Loop Damping		0,20
Actuator knowledge (inertia, torque)		0,01
Resonance amplitude @ stabilization time	rad	0,000149
Angular displacement	rad	0,018
Transient time	s	30
Payload dimensions		
Payload mass	Kg	400
Payload volume	m3	4,05
Mirror size max	m	0,3
Sensor fo	Hz	60
Optical bench f0	Hz	80
Scan mechanism f0	Hz	40
Fast steering mechanism f0	Hz	200
Mirror f0	Hz	110
Detection		
Number of columns (ACT)		224
Detector Frame frequency	Hz	1257
Geometrical performance		
GSD	m	1000
IFOV	rad	2,78E-05
Swath ACT	m	2,24E+05
Swath ALT	m	2,24E+05
Acquisition		
Navigation time	s	3,00E+02
Dwell time	s	1,78E-01
TDI number		100
Time frame (mission)	s	7,95E-04

Expected ASD without LOS stabilization



Expected ASD with LOS stabilization (APE, RPE, PDE)



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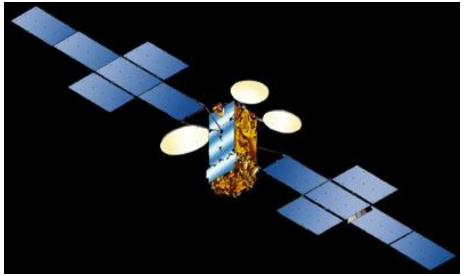
2. HOSTED PAYLOAD MISSION SURVEY AND REQUIREMENT ANALYSIS

MISSION SELECTION

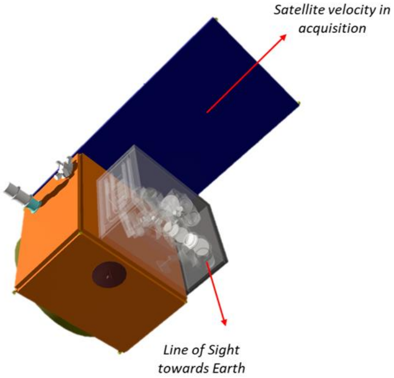


MULTI SPECTRAL INSTRUMENT ON GEO PLATFORM

- The hosted IR imager is a step and push broom acquisition with a scan mirror, with improved agility
- LOS stabilization based on fast steering mirror and gyro data, with SCAN mirror encoder.
- Image processing as a verification

SMALL HYPERSPECTRAL IMAGER ON LEO PLATFORM

- Pushbroom Interferometer in UV/VIS/SWIR
- LOS stabilization system should increase the stability of the low cost platform
- Long acquisition durations (10-20s) with or without LOS slow-down



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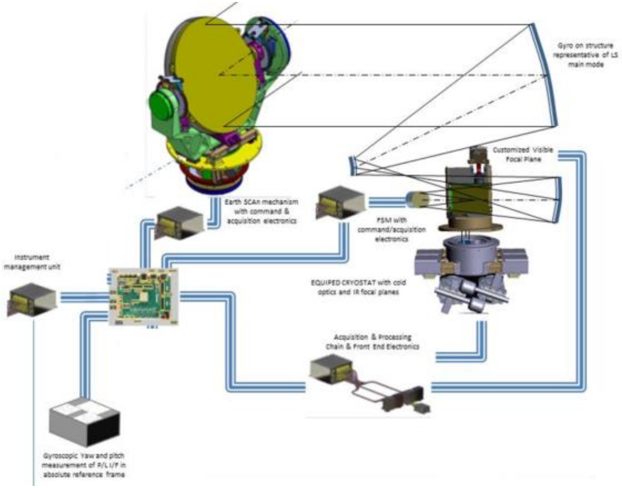
3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN

3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN
ARCHITECTURE

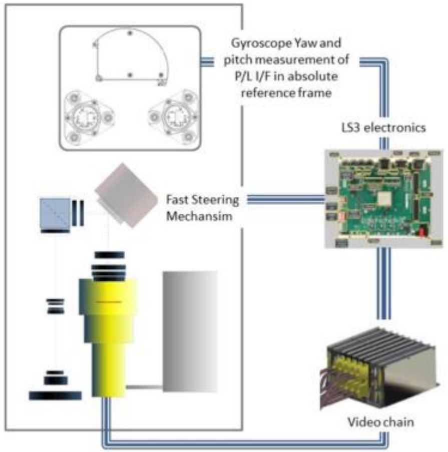
MULTI SPECTRAL INSTRUMENT ON GEO

- The main principle of the system is to control a synthetic line of sight reconstructed in real-time from the available sensors, calibrated using on-ground image processing.
- two axis gyroscope
- scan mirror for Earth scanning
- fast steering mirror for the stabilization
- Image processing for verification. .



HOSTED STATIC INTERFEROMETER

- The main principle of the system is to control a synthetic line of sight reconstructed in real-time from the available sensors, calibrated using on-ground image processing.
- Two axis gyroscope
- Fast steering mirror for the stabilization
- Image processing for verification



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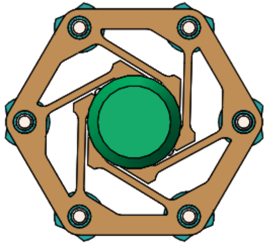
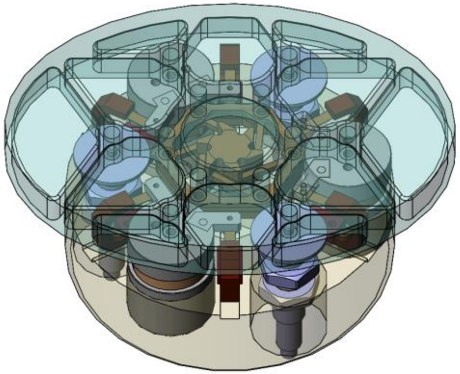
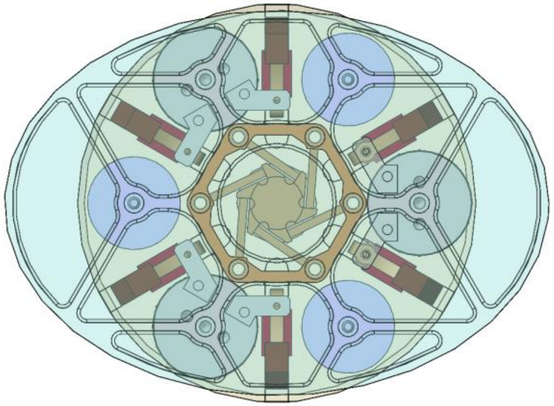
3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN
FAST STEERING MIRROR DESIGN (CSEM)

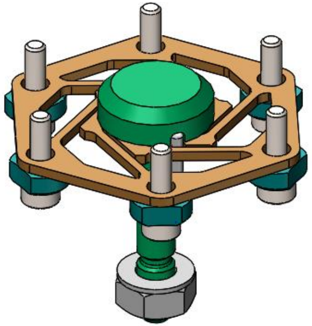
FSM OVERVIEW

- Design based on voice coil actuators for application versatility
- Design is compatible for Eddy current sensors or capacitive sensors according to the application
- Compact configuration to accomodate volume with actuators / sensors at 120°
- Central membrane is main interface between the actuators and the mirror
- Zerodur mirror type considered as baseline (mechanism design compatible with cylindrical or elliptical mirror)
- No launch lock mechanism









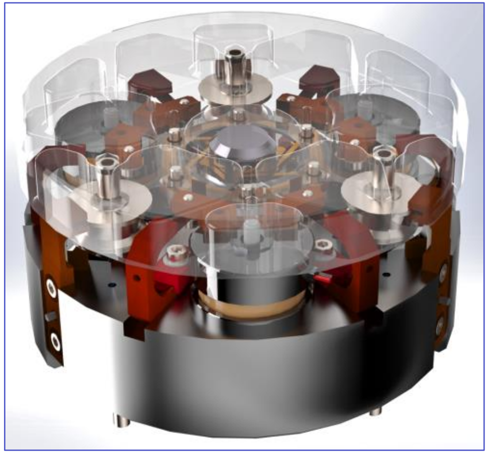
FSM shown with elliptic mirror 82mm x 58mm

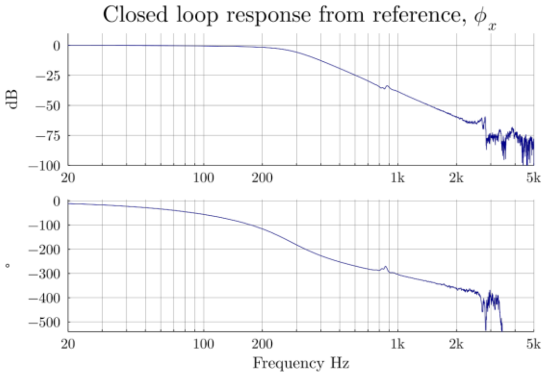
4. LINE OF SIGHT STABILIZATION SYSTEM DESIGN

FAST STEERING MIRROR PROTOTYPE

- COMPACT **FAST-STEERING MIRROR MECHANISM (FSM)** FOR CONTROLLING THE POSITION AND STABILITY OF A PLANAR MIRROR : ENGINEERING BREADBOARD MODEL (EBB) MANUFACTURED
  - Reference specifications from ISABELA static interferometer case
  - Designed with the objective to ease the manufacturing process
  - Actuation of mirror with the use of three voice coils arranged at 120°
  - Capacitive sensors for highest sensitivity and resolution (Easy adaptation for Eddy current sensors)

- TEST CAMPAIGN CARRIED OUT TO CHARACTERIZE BREADBOARD AND EVALUATE PERFORMANCE





Characteristics	FSM performance
Optical angular range (Funct/Max)	±2.4 mrad / ±5.8 mrad
Number of actuators / type	3 / Voice coil
Sensor type	Capacitive
Mirror diameter	60 mm
Typ. Resolution in closed loop	0.34 µrad
Typ. Stability	0.02 µrad up to 100Hz 0.16 µrad at 7'800 Hz
Typ. Repeatability	1 µrad
Dimensions	Ø60 mm x 45 mm
Weight	<200g with Zerodur mirror
Stiffness in Z	0.508 N/µm
Resonant frequency	130 Hz
Operation Voltage/control signal	±10 V
Operating current	±2.5 A

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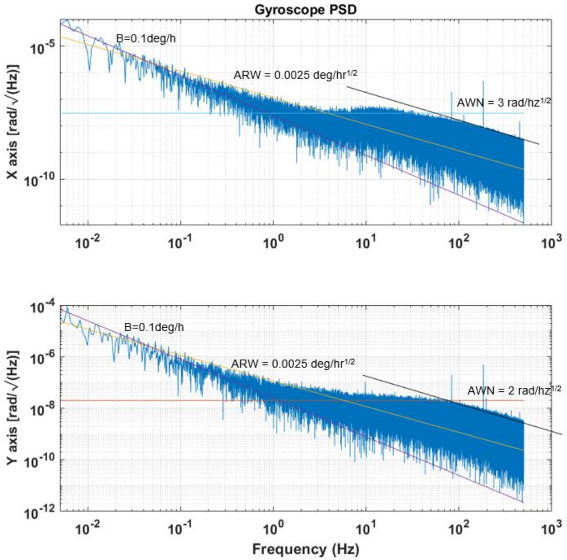
3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN
HIGH FREQUENCY INERTIAL SENSOR (INNALABS)

PROTOTYPE DEVELOPED FOR THE ISABELA PROJECT
- Based on CVG technology
- Prototype developed to be used in the breadboard
- Accuracy as expected, bandwidth (>150Hz)

Parameter	Unit	Value
		GI-CVG-N2230D
Number of Axis		Two
Output Format		Digital
Output Interface		Asynchronous RS422 (Note #1)
Output signal rate	Hz	7900
Measurement Range	deg/sec	± 1
Bandwidth	Hz	≥ 600 (-3dB)
Maximal phase lag at L3S cut off frequency (60 Hz)	deg	≤ 15
In run Bias Stability (room temp. 1σ)(180 Secs)	deg/hr	0.02 typical
Bias stability, full temperature range, 1σ	deg/hr	≤ 10
Bias repeatability, turn-on to turn-on, 1σ	deg/hr	1 typical
Angular Random Walk (steady conditions)	deg/√hr	0.002 typical
Quiescent Noise (1 – 100 Hz), RMS	deg/sec	≤ 0.01
Scale factor error, full temperature range, 1σ	ppm	≤ 3,500
Scale factor Linearity	ppm	≤ 1500



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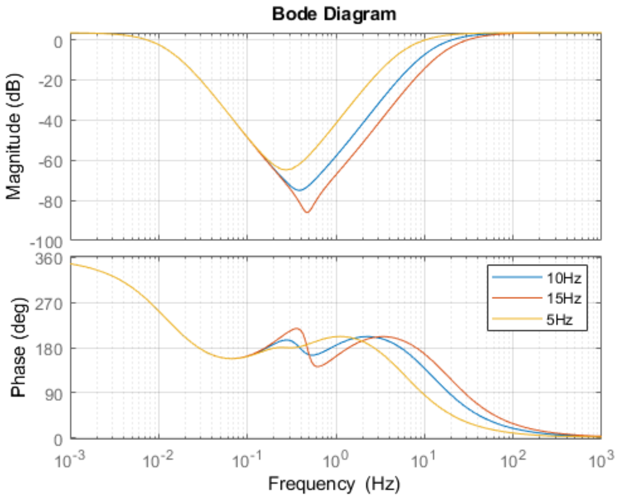
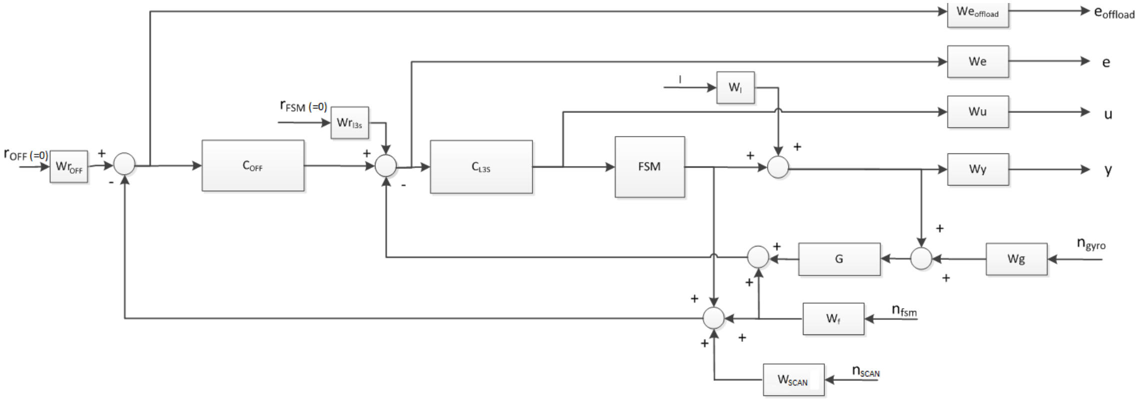
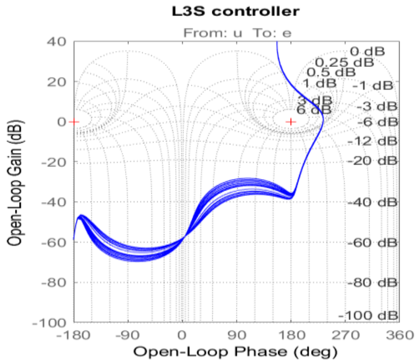
3. LINE OF SIGHT STABILIZATION SYSTEM
CONTROL DESIGN

CONTROLLER ARCHITECTURE

- The controller architecture involves
  - large band controller
  - Tight band components at fixed frequencies to compensate microvibrations
  - Prefiltering of gyroscope drift to avoid FSM saturation
- H-infinity structured synthesis







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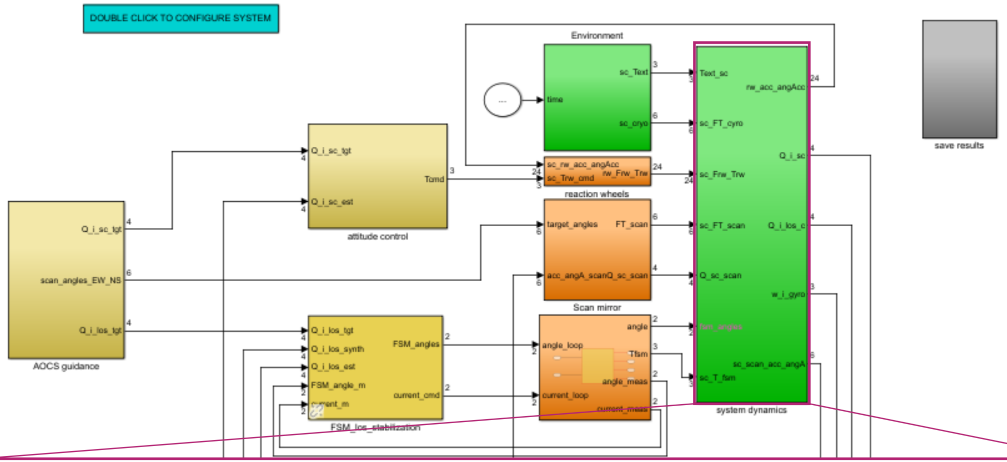
3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN

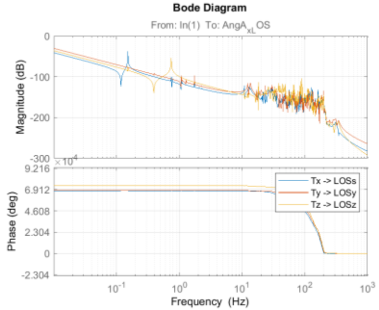
HIGH FIDELITY SIMULATOR

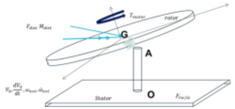
MAIN ELEMENTS

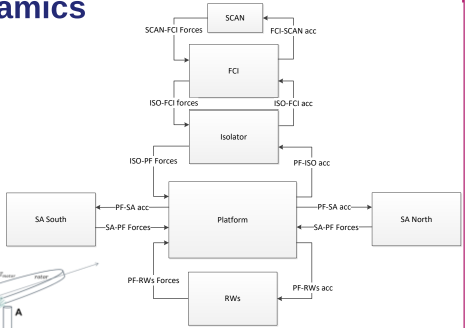
- System dynamics: integrated optical-mechanical model of the platform and the payload.
- Environment: orbit model to and disturbance torques.
- Guidance: Nadir pointing and the scan mirror guidance law.
- Attitude and LOS estimation: star tracker model, image-processing and gyro model.
- Attitude control
- Attitude determination
- FSM LOS stabilization: line of sight control algorithm for the fast steering mirror.
- Reaction wheel flexible dynamics with microvibrations
- Scan mirror: closed loop model with dynamics, electronics and internal controller.
- Fast Steering Mirror: dynamics, electronics and internal control of the scan mirror.



Attitude dynamics







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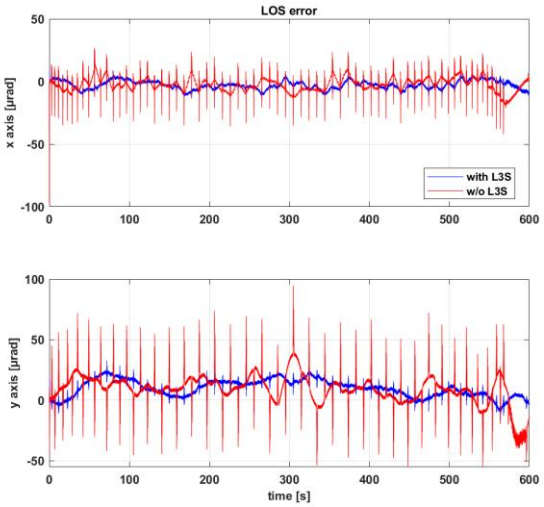
3. LINE OF SIGHT STABILIZATION SYSTEM DESIGN
PERFORMANCE ASSESSMENT

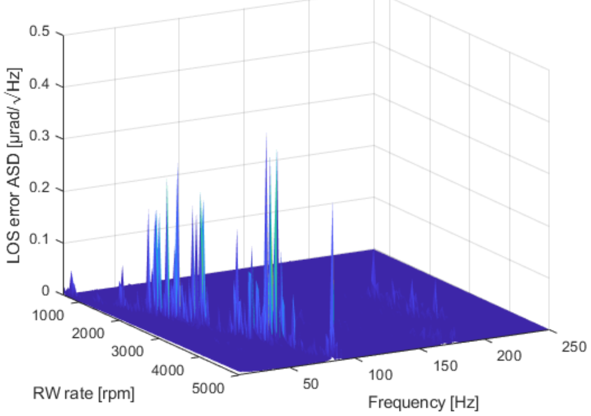
PERFORMANCE ASSESSMENT

- Improvements of performance at LOS level with respect to the S/C level
- Stability is improved on worst case microvibration assessements and for longer term performance requirement, thanks to tight band controller component

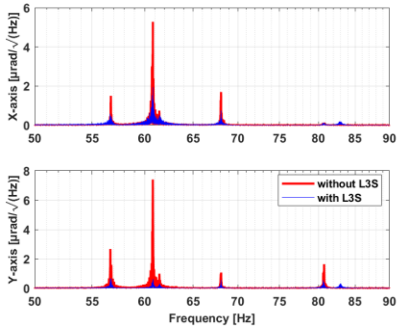
PDE 180ms (3 sigma)	Requirement	SC	LOS
nominal	8.4 µrad	4.6 µrad	2.8 µrad
RW worst case	8.4 µrad	34 µrad	9 µrad



Nominal simulation LOS/SC



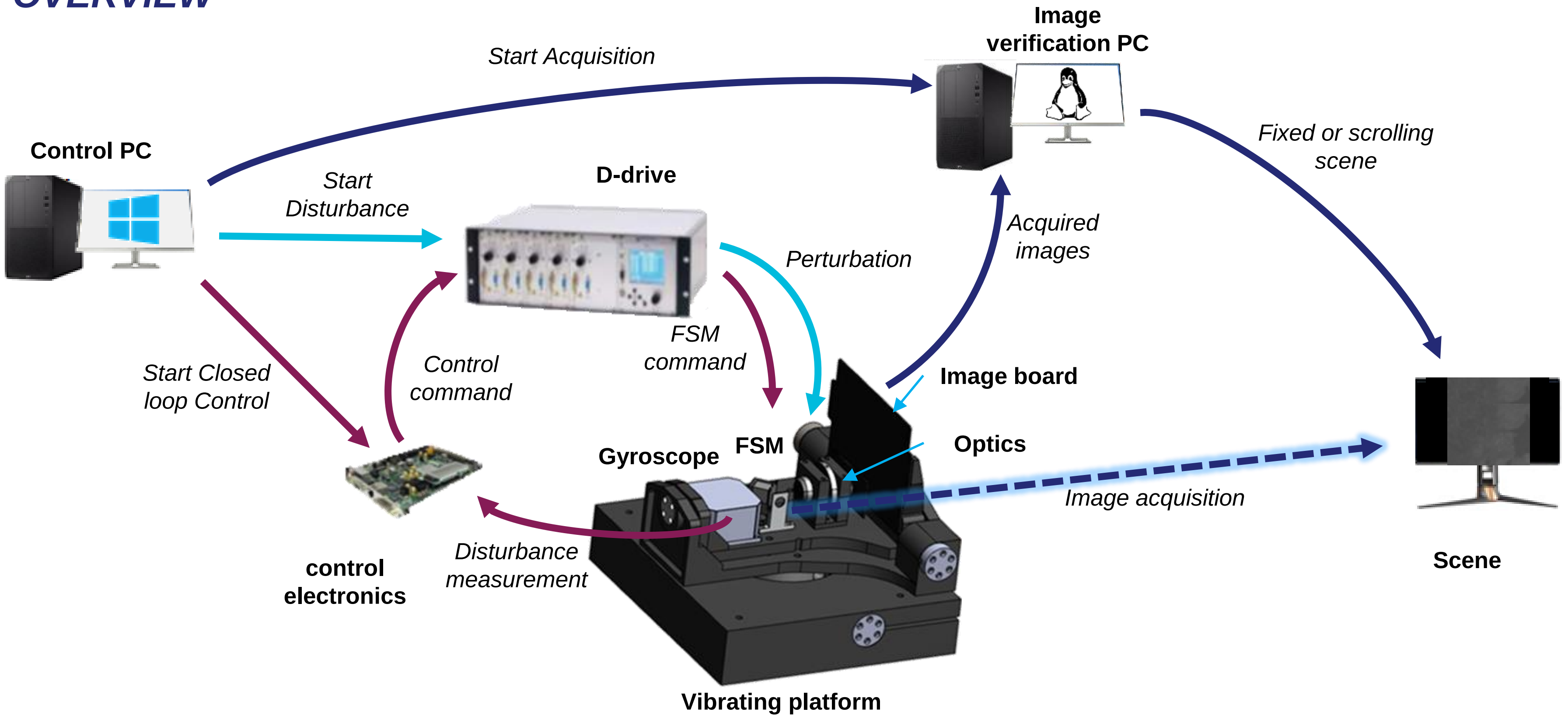
LOS error ASD for each wheel rate



Reduction of microvibration disturbances at LOS level

4. THE ISABELA BREADBOARD

4. THE ISABELA BREADBOARD
OVERVIEW



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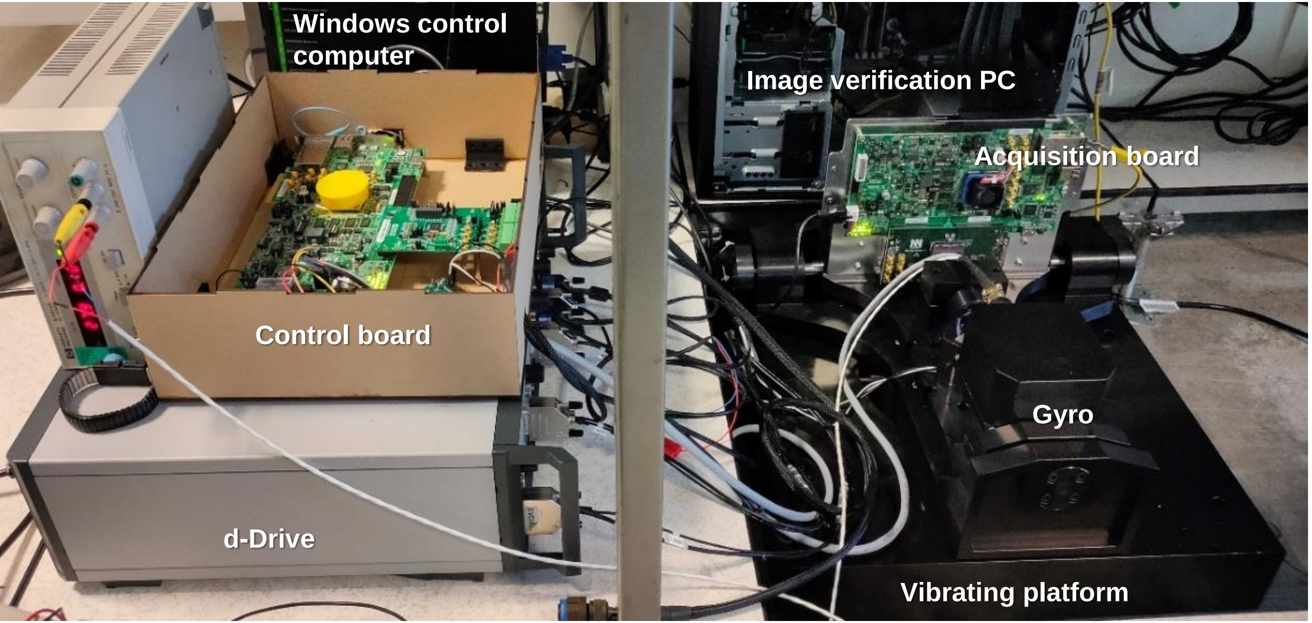
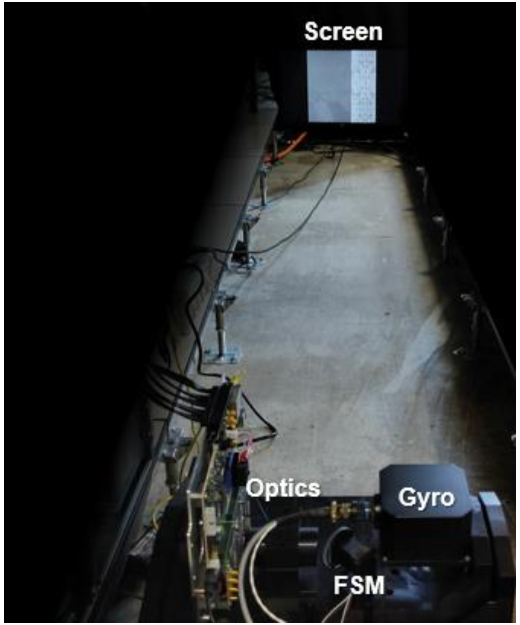
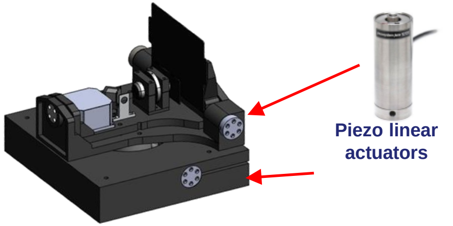
4. THE ISABELA BREADBOARD
PHOTOS



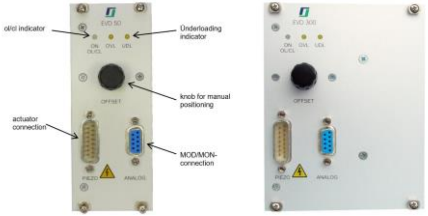


4. THE ISABELA BREADBOARD
MAIN COMPONENTS



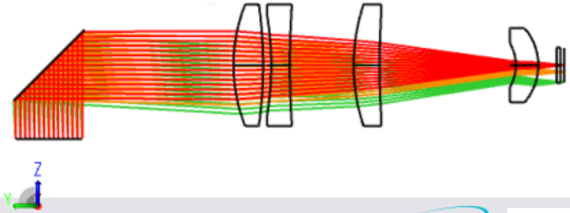
VIBRATING BENCH
- Generate the disturbance on the image and stimulates the gyroscope
- Ball bearing 2 axis mechanism
- 2 Piezoelectric stack actuated in closed loop

FAST STEERING MIRROR
- Jena Piezo System PSH-2-SG two axis piezoelectric steering mechanism
- High stiffness (resonance > 600Hz)
- Mirror of 50mm diameter mounted



D-DRIVE
- 4 channels piezoelectric digital controller for
- Vibrating bench control in open/closed loop
- FSM Amplifier

OPTICS
- The cylinder can be displaced in the optical axis to adjust the focus at the screen distance (2-4m)
- Fast steering mirror with 45° incidence at 50mm from the last lens



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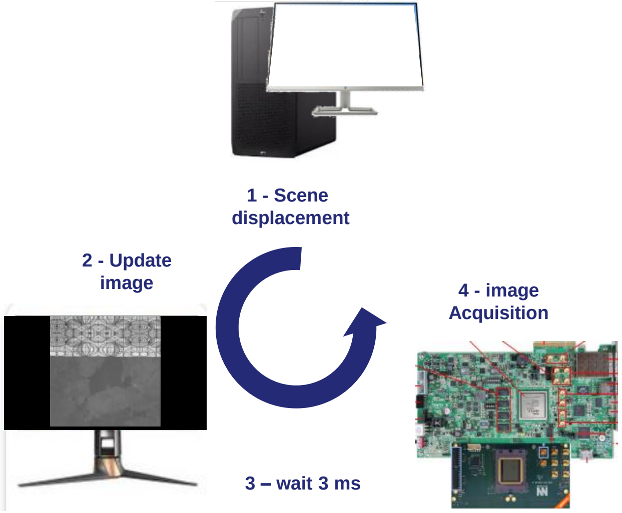
4. THE ISABELA BREADBOARD
MAIN COMPONENTS

/// Main principle

- The control PC read, crop and displace (if scrolling scene) the desired image
- Display on the screen using the SDL2 library with the VSYNC
- Wait 3 ms to allow the screen refresh
- Command the image acquisition

Image acquisition and scene

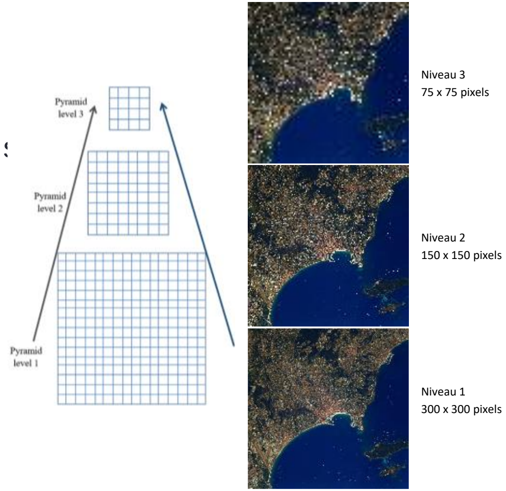


Scene on high frequency screen

Image Acquisition Board

/ IMAGE PROCESSING

- Used to estimate the stability of the line of s
- Pyramidal iterative optical flow
- Accuracy better than 3% of pixel

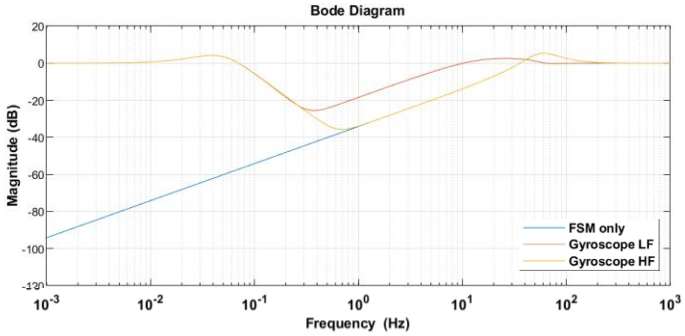


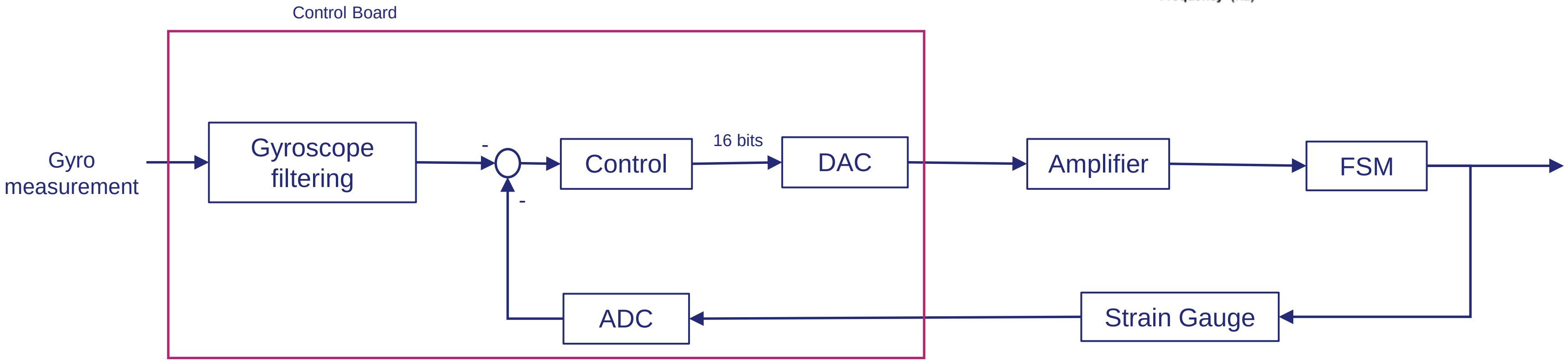
4. THE ISABELA BREADBOARD
CONTROLLER ARCHITECTURE

/// Control algorithm

- Control architecture based on FSM in closed loop with the strain gauge and the gyroscope measurement in open loop
- The controller is implemented as a state space system

Disturbance rejection function

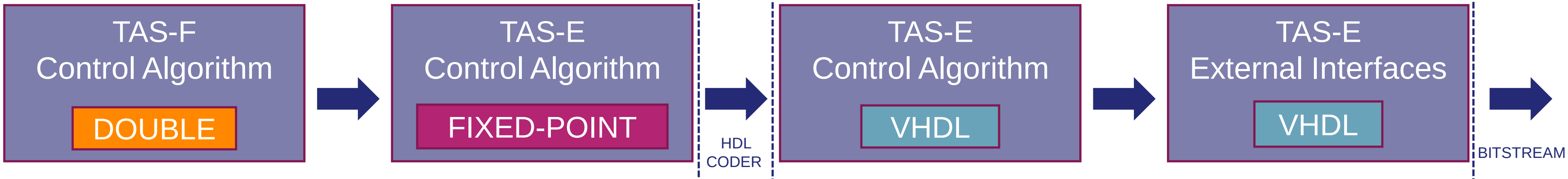




4. THE ISABELA BREADBOARD
CONTROL BOARD WORKFLOW (TAS-SPAIN)

PHASE 1 (MATLAB/SIMULINK)

PHASE 2 (VIVADO)



- Analysis
- Quantification
- Simulations
- Iterations

- Integration
- VHDL Simulations
- Synthesis
- P&R

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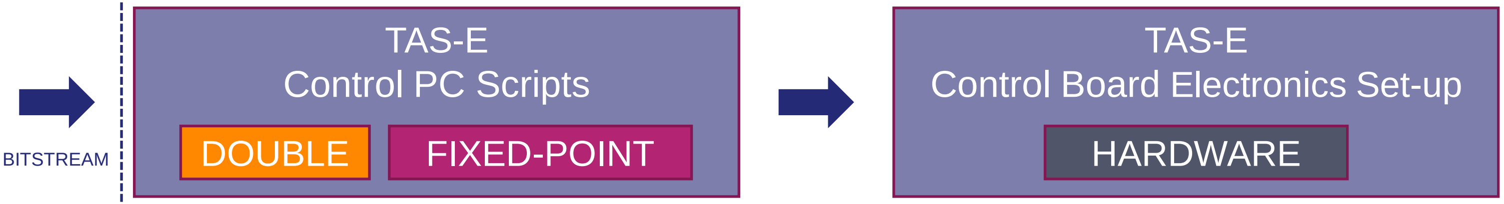
4. THE ISABELA BREADBOARD
CONTROL BOARD WORKFLOW (TAS-SPAIN)

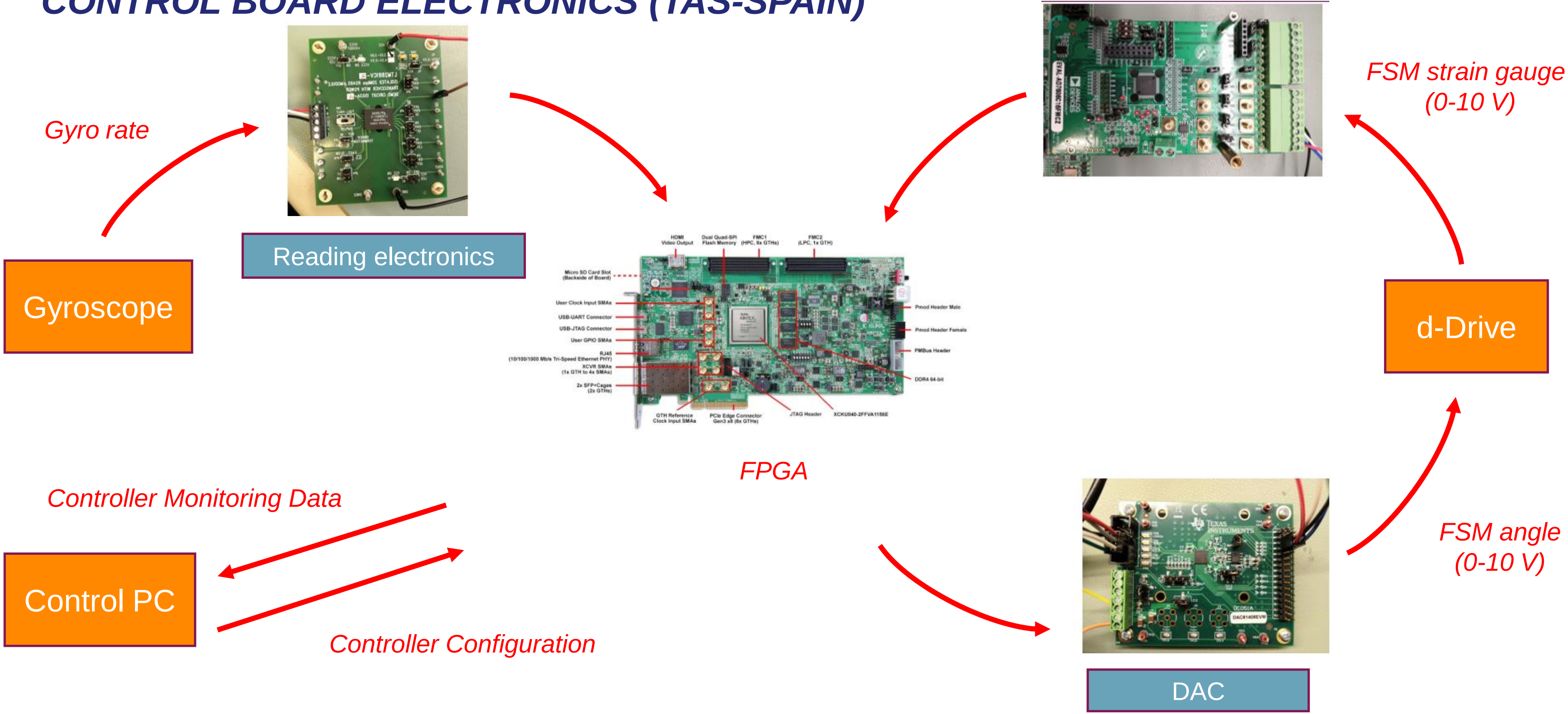
PHASE 3 (OCTAVE + LAB)



- Set-up Building
- Testing

4. THE ISABELA BREADBOARD

CONTROL BOARD ELECTRONICS (TAS-SPAIN)



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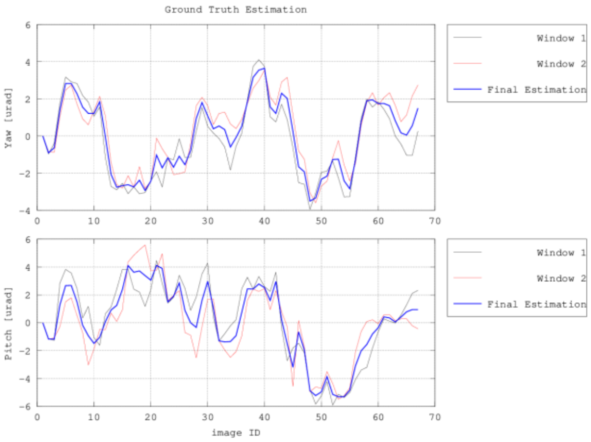
4. THE ISABELA BREADBOARD
TEST RESULTS

Image processing Test
- No disturbance
- No controller

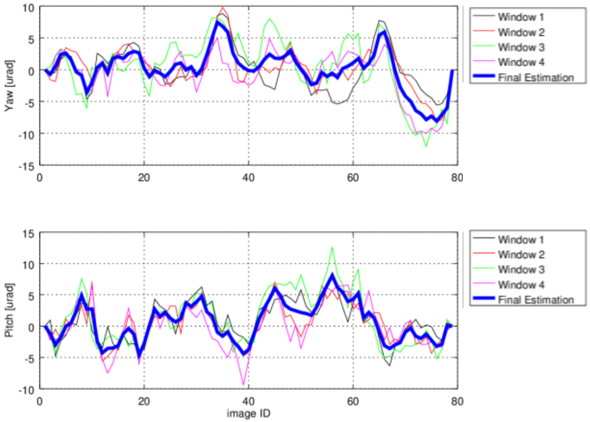
Scene type
- Ground Truth
- Fixed City scene
- Scrolling City scene

Main results
- Performance in the order of 2-3 µrad (3sigma)

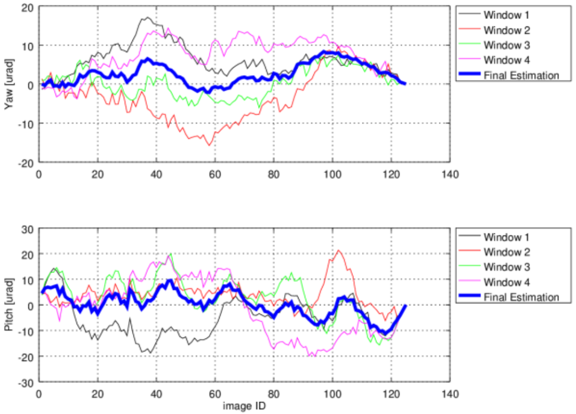
Ground Truth



Fixed City scene



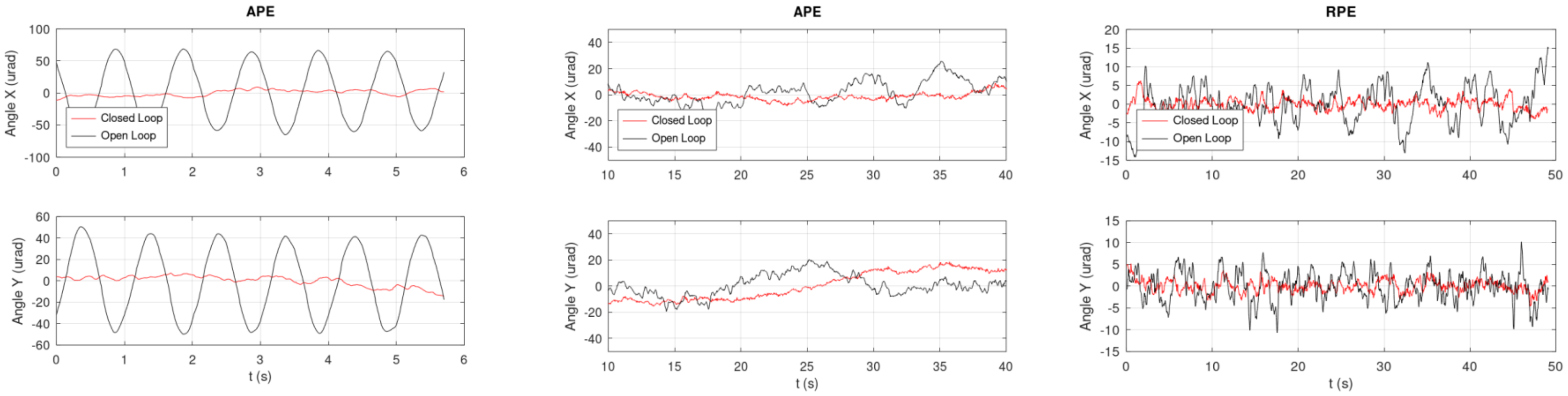
Scrolling City scene



Date : 01/09/2022
Ref : ALS Bench ISABELA
Ref Modele : 83230347-DOC-TAS-FR-006

/// Main results

- Vibration at 1Hz (SADM) => rejection as expected at -20dB
- Static interferometer results => RPE 8.4s S/C [14 10] µrad , LOS [3.8 3.4] µrad



4. THE ISABELA BREADBOARD
TEST RESULTS

Video link

Date: 01/09/2022
Ref: ALS Bench ISABELA
Template: 83230347-DOC-TAS-EN-006

4. THE ISABELA BREADBOARD
MAIN RESULTS EXTRAPOLATION

MISSION SURVEY SUMMARY

- 5 instruments are considered:
  - Static interferometer
  - TDI
  - Small Hyperspectral
  - Multispectral imager
  - GEO Sounder

- Platforms:
  - Nanosatellite 6-16U
  - Microsatellite
  - Telecom Platform LEO
  - Telecom Platform GEO

Instrument	Platform	Driving Pointing stability Requirements	Expected performance
LEO Static Interfero	**Nanosatellite**	7µrad (1sigma) over 8.4s (Goal) 0.7µrad 1-sigma over 8.4s	Performance assessed in the breadboard, the system improve the platform stability by a factor x3 to x5
	Microsatellite medium performance		
	Telecom LEO		
LEO Time Delay Integration Imager	**Any**	1µrad over 1ms	The gain for this type of mission is limited due to the very short time window of the RPE requirement, mainly driven by high frequency micro-vibrations
LEO Hyper-spectral Imager	**Nanosatellite**	6 µrad over 17s	The platform is not compliant, ISABELA enables the implementation of the payload.
	Microsatellite medium perf		The platform almost compliant, ISABELA can provide the additional stability.
	Telecom LEO		The platform not compliant. ISABELA enables the implementation of the payload.
GEO Multi spectral Imager (FCI)	**Telecom GEO**	2.8 µrad over 180ms	As presented in the simulations, the performance is compliant with the requirement with the ISABELA system.
GEO Sounder	**Telecom GEO**	5 µrad (3sigma) over 10s	The platform not compliant. ISABELA enables the implementation of the payload

6. CONCLUSIONS

MAIN ACHIEVEMENTS OF THE STUDY

- Assessing LOS stabilization for several potential hosted payload missions using inertial approaches.
- The first part of the work focused on the main application cases,
  - Multispectral instrument in GEO as a simulation scenario,
  - Static interferometer as a breadboarding scenario.
- On GEO multispectral imager stability performance can be improved for longer performance index (>100ms), and also in presence of payload vibrations
- Breadboard Design and manufacturing
- The stabilization results eventually confirmed the results obtained by analysis with representative spacecraft pointing disturbances.
- Extrapolation of results allowed to identify the future hosted payload missions that will benefit from ISABELA system.